TM 10-575

WAR DEPARTMENT

U.S. Dept. of Army

TECHNICAL MANUAL

# DIESEL ENGINES AND FUELS

July 25, 1941

[illegible]

TECHNICAL MANUAL No. 10-575

WAR DEPARTMENT, WASHINGTON, July 25, 1941.



# DIESEL ENGINES AND FUELS

Prepared under direction of
The Quartermaster General



SECTION I

## DIESEL FUNDAMENTALS

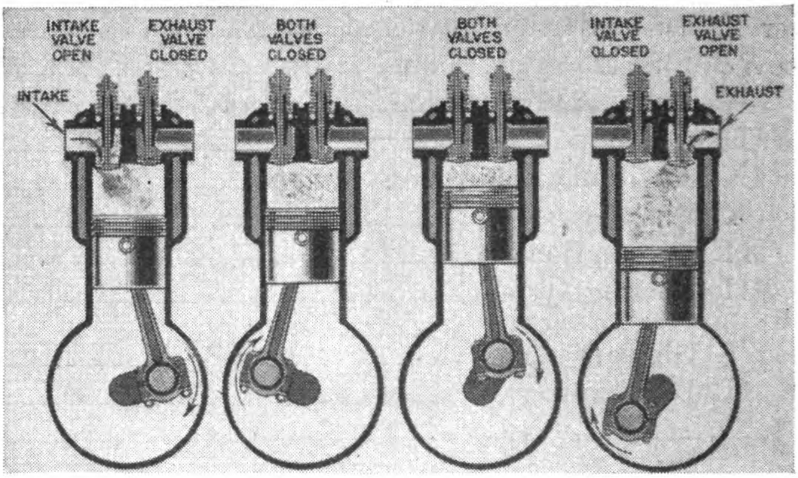


**1. General.**—*a.* A Diesel engine is commonly recognized as an internal combustion engine in which the fuel is ignited by the heat of compression. Actually the Diesel engine is characterized by thermodynamic principles which are beyond the scope of this manual. Contrary to popular opinion, it is not a new invention. In 1892

Dr. Rudolph Diesel, a German engineer, seeking an engine having greater fuel economy than the steam and gas engines in use at that time, patented an internal combustion engine bearing his name.

*b.* Early Diesel engines, because of their great bulk and low speeds, were employed only in place of the low efficiency steam engines used for generating electricity and providing industrial power. However, their superiority over the steam engine soon attracted the attention of the marine world in which they have long had extensive application.

*c.* The high speed automotive Diesel engine, which this manual will consider primarily, is of comparatively recent origin. Except for the method of igniting and of supplying fuel, it is generally similar to the modern automotive gasoline engine. For this reason it is recommended that the reader become familiar with the principles of the gasoline engine. Many years of consistent research and experience, however, were necessary before strong, light metals and satisfactory fuel injection systems were developed which made the Diesel engine as compact and flexible as the gasoline internal combustion engine.




① Suction. ② Compression. ④ Exhaust. ③ Power.

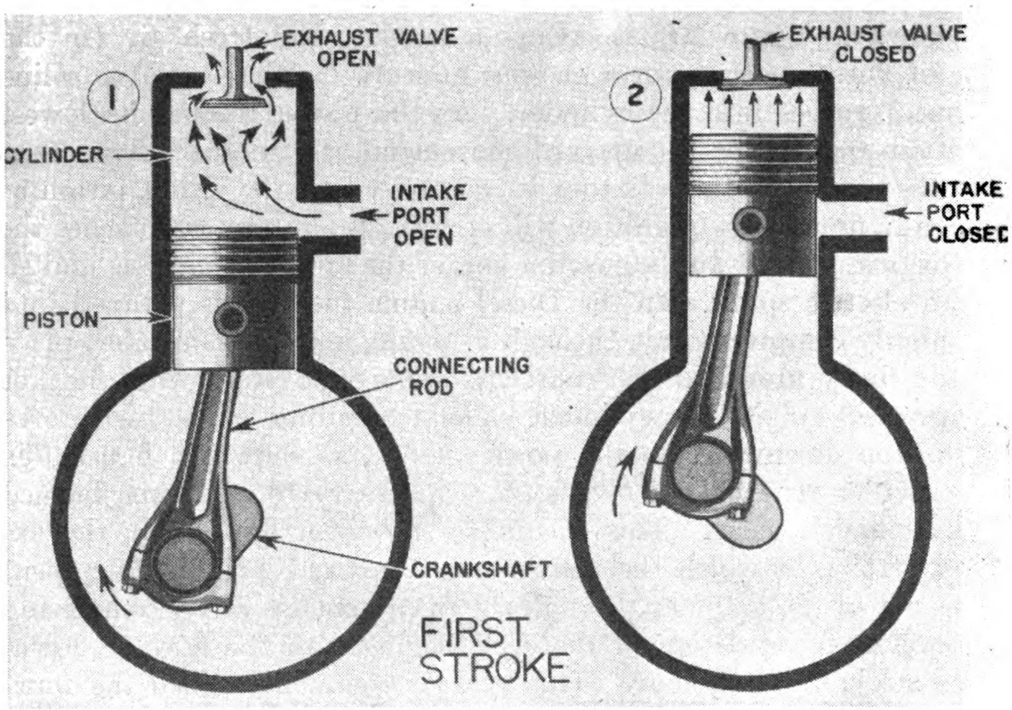
FIGURE 1.—Sequence of events occurring in four-stroke cycle in both gasoline and Diesel engines.

**2. Definition of terms.**—For definition of terms pertaining to Diesel engines, see appendix I.

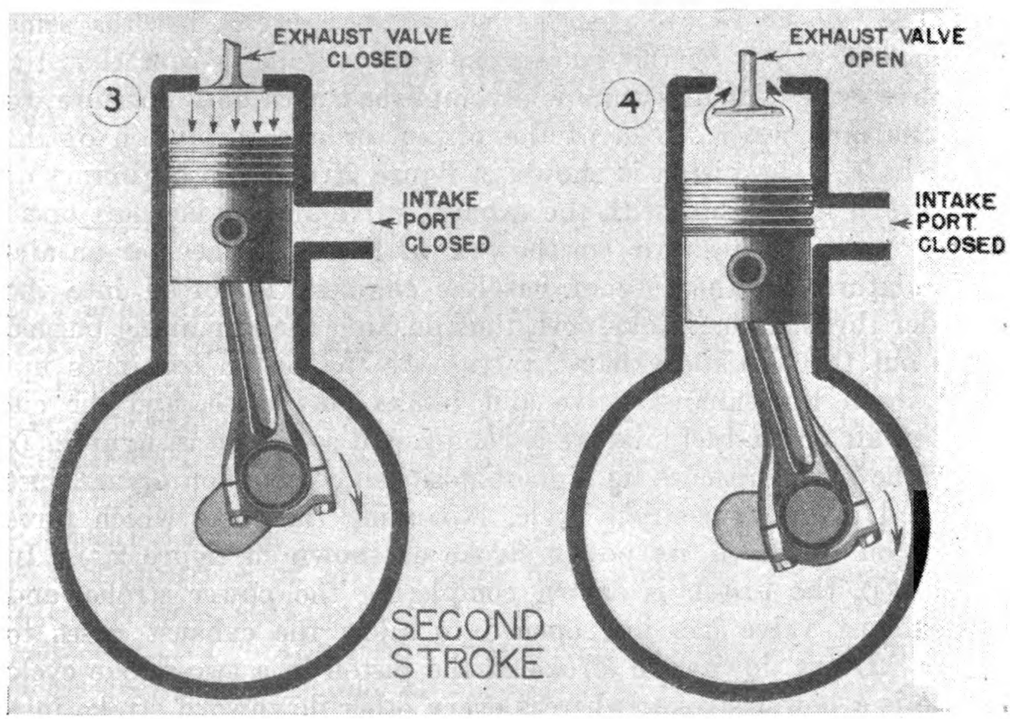
**3. General comparisons of internal combustion engines.**—*a.* The operating principle of the gasoline (Otto) engine and the compression-ignition (Diesel) engine are very similar. Figure 1 illustrates the sequence of events common to both types of internal combustion engines.

*b.* When the intake valve is open and the piston moves downward as shown in figure 1①, it creates a suction, and fresh air (in the case of Diesel engines) or a gaseous mixture (in the case of gasoline engines) rushes into the cylinder. As the piston reaches its lowest position and begins its upward movement, the intake valve closes and the air or air-fuel mixture is compressed by the rising piston as shown in figure 1②. Ignition will occur as the piston approaches the top of this stroke. In the gasoline engine the air-fuel charge is ignited by an electric spark. In the Diesel engine the fuel is sprayed into the highly compressed air through a nozzle, and ignition takes place as the finely atomized fuel particles come in contact with the hot compressed air in the cylinder. The expanding gases then force the piston downward on the power stroke, as shown in figure 1③. In order to renew these events, it is necessary to expel the burned and expanded gases. This occurs as shown in figure 1④, the exhaust stroke, in which the piston moves upward, pushing the spent gases out of the cylinder through the open exhaust valve, completing the cycle. A repetition of the cycle begins with the next or downward stroke of the piston. This cycle is commonly called the four-stroke cycle, and two revolutions of the crankshaft are required to complete it.

*c.* The two-stroke cycle engine, shown in figure 2, has the same sequence of events as the four-stroke cycle engine, except that the complete cycle of four events is accomplished with only one upward and one downward stroke of the piston, or one revolution of the crankshaft. The piston is shown in figure 2①, at the beginning of its upward movement, with the exhaust valve and intake port open. In this position, fresh air (in the case of Diesel engines) or an air-fuel mixture (in the case of gasoline engines) is forced into the cylinder through the intake port, thus pushing the remaining burned gases out through the exhaust valve. As the piston continues upward, both the exhaust valve and intake port close, and the entrapped air or air-fuel mixture is compressed as shown in figure 2②. After the piston reaches its highest position, combustion occurs, just as it did in the four-stroke cycle, expanding the gases which force the piston down on its power stroke as shown in figure 2③. In figure 2④, the piston is shown completing the power stroke, and the exhaust valve has just opened to allow the exhaust gases to escape. Every downward stroke of the piston in a two-stroke cycle engine is a power stroke; whereas every other downward stroke in a four-stroke cycle engine is a power stroke.




① End of exhaust and intake. ② Compression.




③ Power. ④ Beginning of exhaust.

FIGURE 2.—Sequence of events occurring in two-stroke cycle gasoline and Diesel engine.

*d.* An average valve timing for a two-stroke cycle high speed Diesel engine is shown in figure 3.

*e.* Figure 4 shows a typical four-stroke cycle Diesel valve timing diagram. This differs from the timing of high speed gasoline engines only in that the inlet closes about 10° earlier. The reasons for this

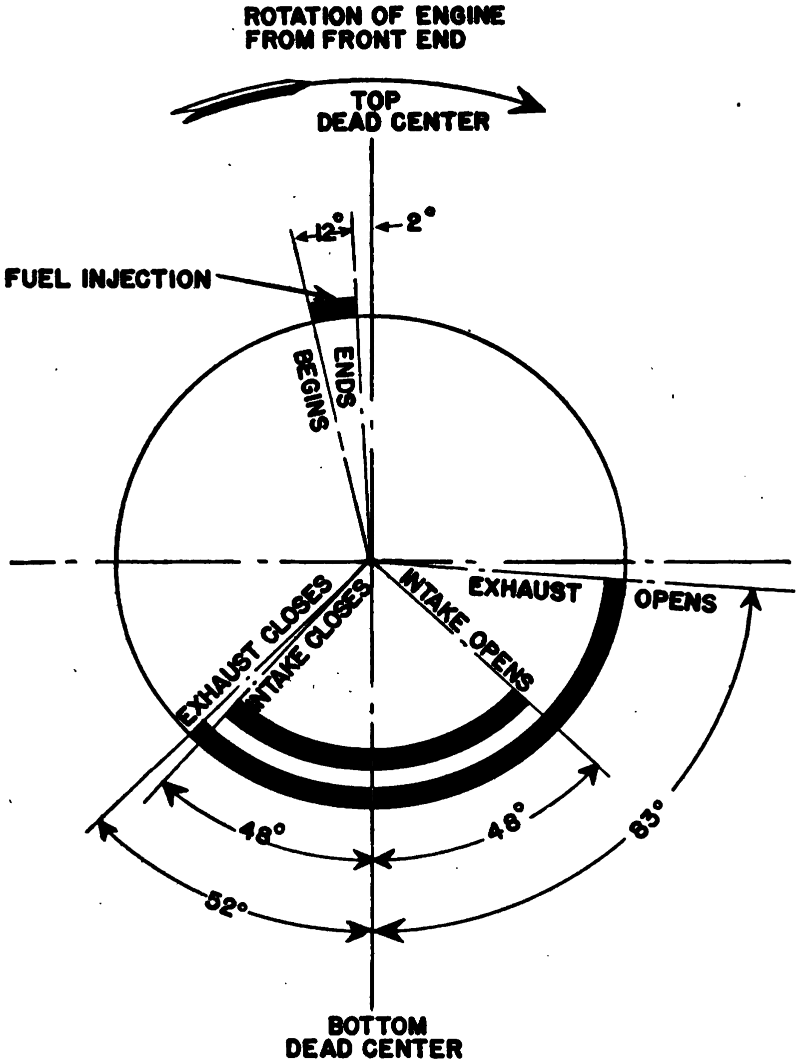



FIGURE 3.—Valve timing for two-stroke cycle Diesel engine.

difference probably are that Diesel engines do not turn quite as fast as passenger car engines and that in the gasoline engine there is an accumulation of gasoline in the inlet manifold which is being turned into gas, and that the resulting pressure increase in the manifold makes it advisable to hold the intake valves open somewhat longer.

**4. Compression.**—*a.* One of the basic differences between the gasoline engine and the Diesel engine is in the compression stroke. The gasoline engine compresses a mixture of gasoline and air to a low pressure at a temperature below the ignition temperature of the fuel mixture. The mixture is then ignited by an electric spark

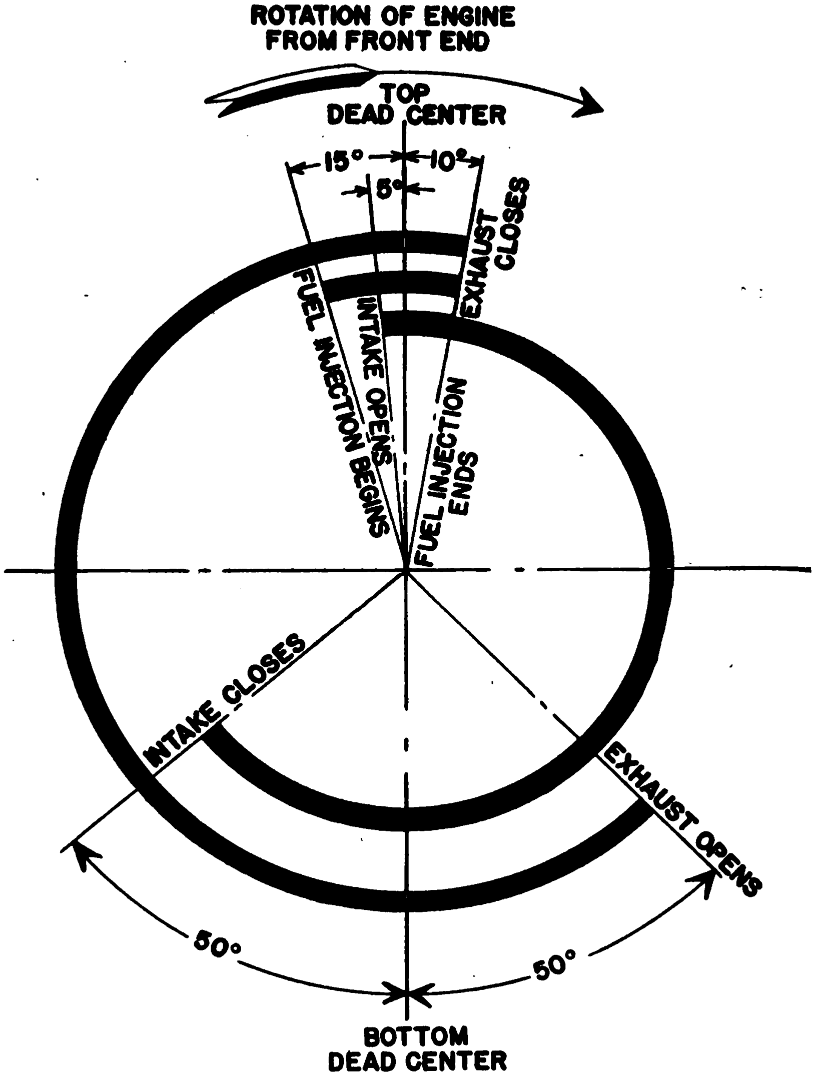


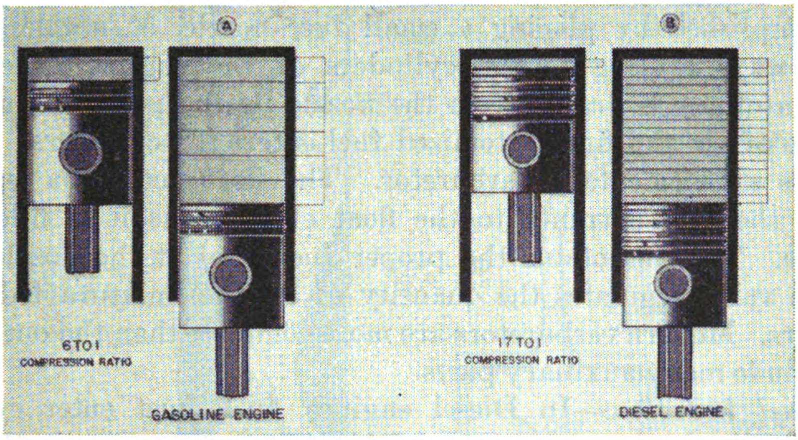

FIGURE 4.—Valve timing for four-stroke cycle Diesel engine.

just before the beginning of the power stroke. This type of engine is referred to as the Otto cycle engine.

*b.* The Diesel engine compresses air to extremely high pressures and temperatures. At the top of the compression stroke, just as the fuel is injected, the temperature rises to as high as 1,000° F. This extreme heat aids the vaporization of the atomized fuel and

ignites the fuel without the aid of a spark. These high compression pressures account for the fuel economy of Diesel engines, because an increase of 1 pound per square inch in compression pressure increases the combustion pressure about 4 pounds per square inch.

*c.* The amount of compression in an engine cylinder is determined by the compression ratio. A compression ratio of 6 to 1 indicates that the volume above the piston is 6 times greater when the piston is at the bottom of its stroke than it is when the piston is at the top. Figure 5 illustrates typical compression ratios of gasoline and Diesel engines. It may be seen that the compression ratio of Diesel engines is considerably higher than that of gasoline engines.




① Gasoline engine. ② Diesel engine.

FIGURE 5.—Comparison of the compression ratios of gasoline and Diesel engines.

**5. Air-fuel ratios.**—*a.* The gasoline engine burns a mixture of gasoline and air which is mixed outside the engine, and introduced into the cylinders in the form of a combustible gas. Experience has shown that this gas, in order to burn properly, must consist of not less than 12 or more than 17 parts of air to 1 part of fuel by weight at sea level. This proportion varies with different fuels. Thus, the amount of air in proportion to the amount of fuel is limited, which means that each particle of fuel can come in contact with only a limited number of particles of oxygen, making complete combustion of the gaseous mixture difficult. To avoid detonation (too rapid burning) the gas must not be compressed much beyond 150 pounds per square inch.

*b.* In the Diesel engine a varying amount of fuel oil is mixed with a constant amount of compressed air inside the cylinders. Since the Diesel engine is controlled by varying the amount of fuel injected into the cylinders, instead of varying the amount of air-

fuel mixture as in the gasoline engine, there is usually an excess quantity of air in the cylinders for each cycle. Thus, under almost any operating condition, each particle of fuel can come into contact with many more particles of oxygen than it can in a gasoline engine, and the fuel mixture is burned more completely. Air-fuel ratios in Diesel engines range from about 18 parts of air to 1 part of fuel at full load, to nearly 100 parts of air to 1 part of fuel at no load. Any desirable air-fuel ratio is possible in Diesel engines because the quantity of fuel injected into the cylinders is controllable.

**6. Method of fuel feeding.**—*a. Carburetion.*—The primary object of carburetion is to produce a combustible mixture of air and fuel for the gasoline engine under all operating conditions. This is accomplished by placing a small fuel nozzle, or nozzles, in air passageways leading to the cylinders of the engine. The liquid fuel (gasoline) is drawn from the nozzle by the passing air, and a mixture of air and finely atomized fuel enters the cylinders. Figure 6 shows an elementary carburetor. The float acts as a valve by closing the fuel entrance to the float chamber as it is filled with gasoline. This maintains the proper fuel level at the nozzle. The throttle valve regulates the quantity of air-fuel mixture fed to the cylinders. Modern carburetors are more complete than the one shown, and include many auxiliary parts.

*b. Fuel injection.*—In Diesel engines, fuel must enter cylinders that contain highly compressed air. There are two methods of injecting the fuel against the air pressure in the cylinder, air injection and solid injection.

(1) In the air injection method, liquid fuel is maintained under relatively low pressure until just before injection. Then it is forced into the cylinder by an air blast of from 800 to 1,000 pounds per square inch, which is provided by an auxiliary air pump. This was the original method of fuel injection because at the time it seemed to be the only feasible way to mix the fuel and air thoroughly. Today this method is found only in heavy duty stationary engines, and will not be discussed in detail in this manual.

(2) The solid injection method is a direct method, wherein the fuel itself is pumped into the engine cylinders at a high pressure. Fuel line pressures may be as high as 3,000 pounds per square inch, and pressures at nozzle tips may be as high as 20,000 pounds per square inch. This method is used in all modern high speed automotive Diesel engines.

**7. Economy.**—*a.* Much can be said about the economy of Diesel engines. All internal combustion engines produce their power by burning a fuel and converting its chemical energy into heat. This heat causes the gases of combustion within the cylinder to expand and push against the piston, thus transforming the heat energy into mechanical power. The ability to extract more heat energy from Diesel fuel is the real reason for the greater economy of the Diesel engine. Fuel contains a certain amount of heat energy units, usually expressed as B. t. u. (British thermal units), which are equal to 778 foot-pounds of work or energy. This varies from an average of

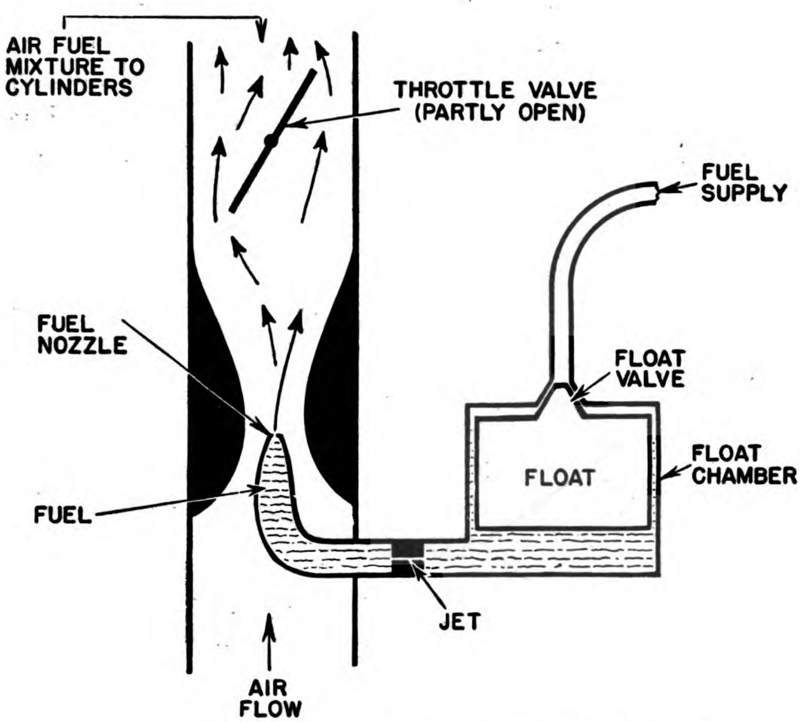


FIGURE 6.—Fuel flow in elementary carburetor.

125,000 B. t. u. per gallon for gasoline, to an average of 142,000 B. t. u. per gallon for Diesel fuel oil. The percentage of B. t. u. actually converted into useful power by an engine compared to the amount consumed is known as its thermal efficiency.

*b.* In the gasoline engine the thermal efficiency will seldom exceed 25 percent, which means that only 25 out of every 100 B. t. u. are actually converted into power, while 75 B. t. u. are lost or wasted because they were never burned, or because their energy was lost in overcoming friction, in pumping losses, in cooling, or in waste heat dissipated through the exhaust.

*c*. In the Diesel engine, thermal efficiencies run as high as 35 percent, which indicates that a greater percentage of the available B. t. u. are utilized than is possible in the gasoline engine. This superior thermal efficiency is also reflected in the fact that the exhaust of all gasoline engines contain a certain amount of carbon monoxide, indicating unburned fuel, which makes them a source of danger to personnel when they are operated in closed spaces. A Diesel engine in perfect operating condition burns its fuel so com-

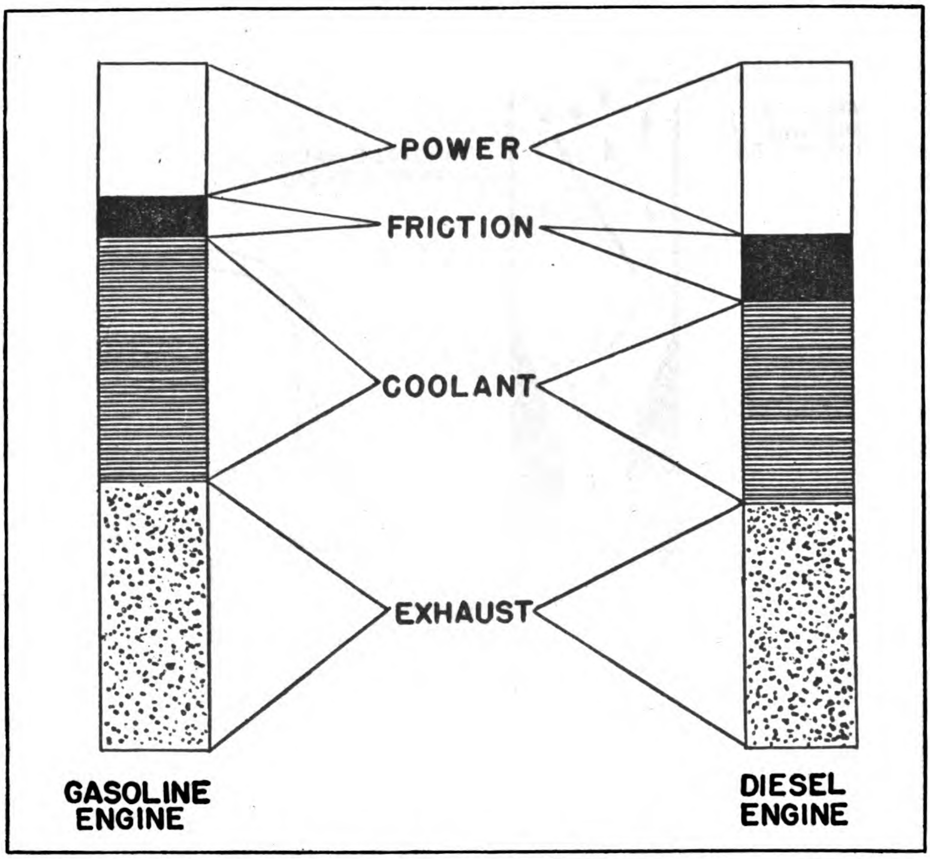



FIGURE 7.—Comparing heat losses and available power of gasoline and Diesel engines.

pletely that the percentage of carbon monoxide gas in the exhaust is comparatively harmless. Figure 7 shows the power and heat losses of the two types of engines. The Diesel engine is particularly efficient at part loads. One manufacturer gives the comparative figures shown in figure 8.

*d*. The Diesel engine does not overheat and lose power when subjected to heavy loads since it depends upon heat for combustion. This is particularly important at slow speeds under heavy loads and accounts for the consistent high torque, or "lugging," character-

istic of the Diesel engine under such conditions. A Diesel engine therefore provides exceptional performance in addition to economy.

**8. Construction.**—*a.* In a general way the design of parts for high speed Diesel engines follow closely that of the corresponding parts for heavy duty gasoline engines which have been described in TM 10–570. However, owing to the high peak pressures and temperatures in the cylinders of Diesels, there is a tendency to deviate from established gasoline engine practice in certain particulars. To withstand the increased stresses developed by high cylinder pressures, it is necessary to add more strength to Diesel engine parts such as frames, cylinders, pistons, connecting rods, and crankshafts than found in gasoline engines. This increases the weight and makes the Diesel engine weigh more per horsepower than gasoline engines.

| LOAD | GALLONS PER HOUR FOR 100 HP ENGINE | | GASOLINE CONSUMPTION OVER DIESEL |
|---|---|---|---|
| | GASOLINE | DIESEL | |
| FULL LOAD (100 HP) | 10.7 | 6.7 | 60% |
| 3/4 LOAD ( 75 HP) | 8.9 | 5.4 | 65% |
| 1/2 LOAD ( 50 HP) | 7.2 | 4.1 | 75% |
| 1/4 LOAD ( 25 HP) | 5.7 | 2.9 | 97% |

FIGURE 8.—Effect of load on economy.

Much help has been received in this respect, however, from metallurgists who have developed metals which are light but very strong.

*b.* The use of through bolts (fig. 9) tying together the cylinder head, cylinder block, crankcase, and main bearing caps has been widely resorted to in Diesel engines. These bolts extend through the engine structure and relieve it of the high tensile stresses. Some manufacturers use heavily ribbed cylinder blocks and crankcases as a means of increasing the strength of the engine structure.

*c.* Under similar service conditions, the rate of wear on the cylinders of Diesel engines is always greater than gasoline engines of the same size and having the same cylinder wall hardness. The gases of combustion get behind the topmost piston ring and force it outward against the cylinder wall with great pressure (some engines 500 pounds per square inch), and cause rather rapid wear at the upper end of the cylinder. Therefore the use of removable cylinder sleeves is a common Diesel practice. Figure 10 shows a wet cylinder

sleeve which is in direct contact with the cooling water. (Note water seals at lower portion of the sleeve.) Uniform cooling of the

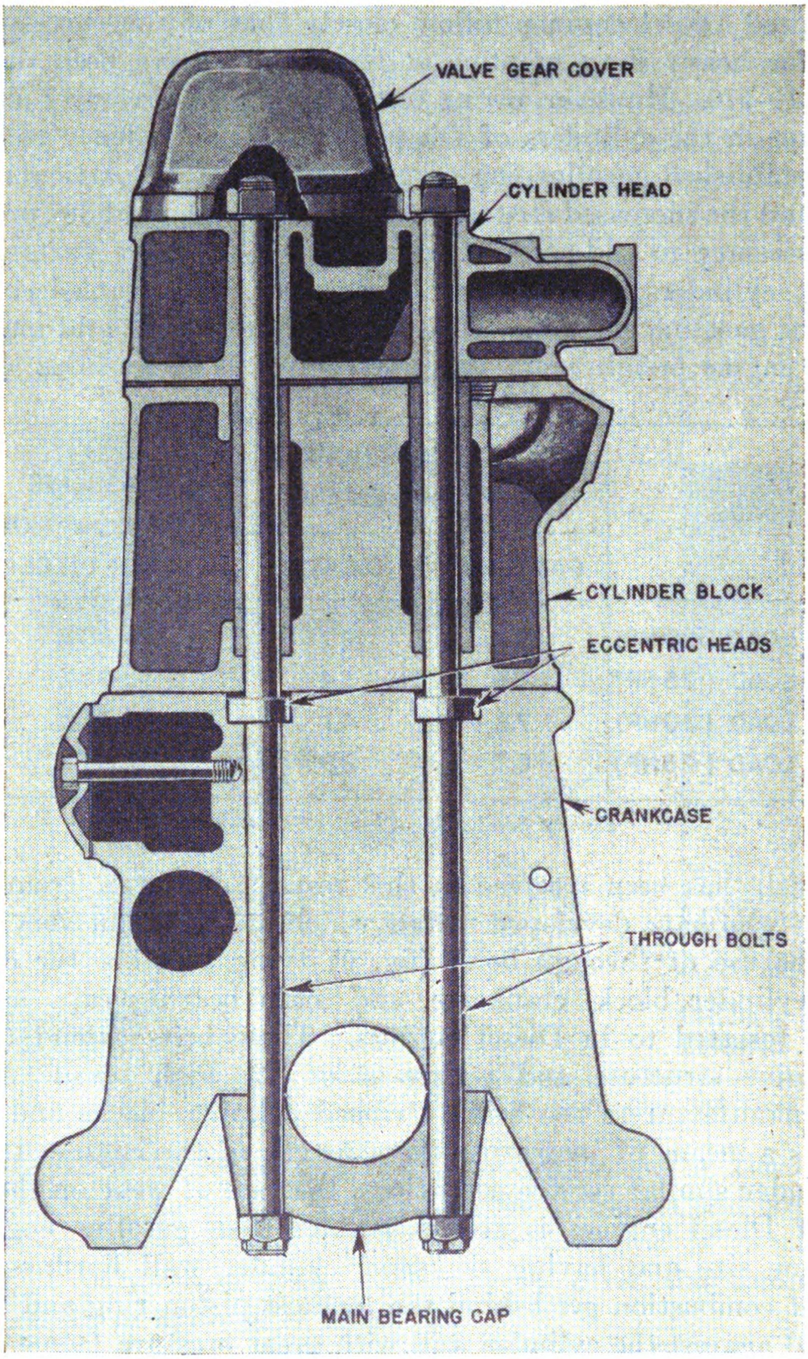



FIGURE 9.—Through bolts.

upper portion of wet sleeves is difficult, except by expensive construction, due to the thick sections of the water jacket and sleeve

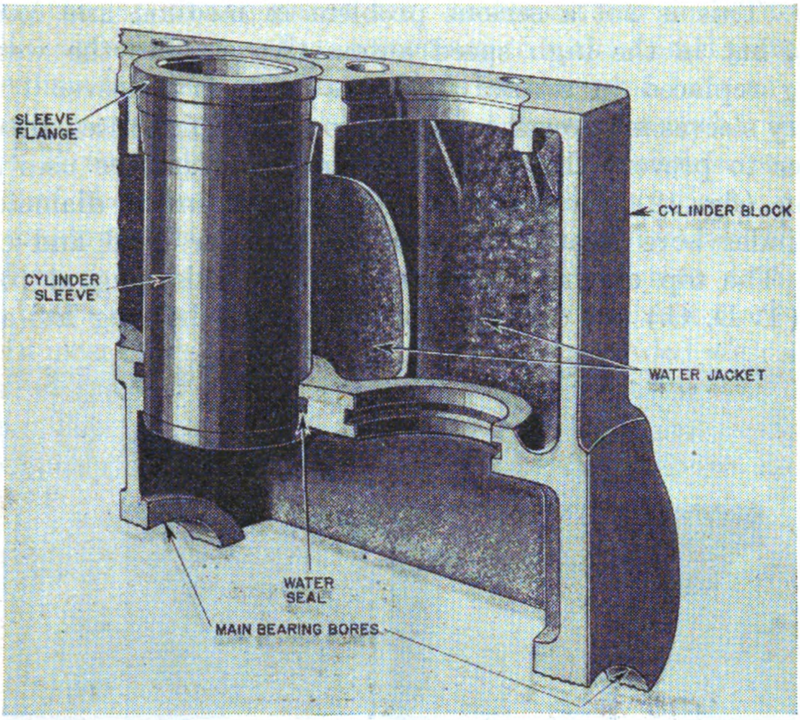



FIGURE 10.—Wet cylinder sleeve.

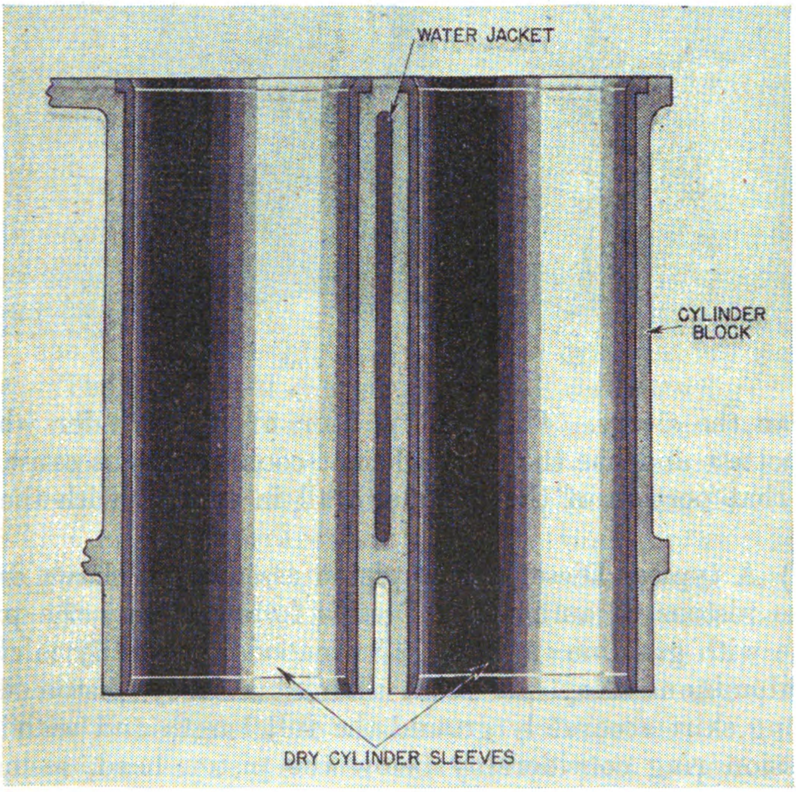



FIGURE 11.—Dry cylinder sleeve.

flanges. This is not a serious problem in medium and low speed engines, but in the high speed automotive engines the wet sleeve is being replaced in several instances with dry sleeves (fig. 11). Even dry sleeves may overheat at the top, and this causes distortions. In order to prevent this distortion one manufacturer uses a short fire ring (fig. 12), having a slightly greater inside diameter than the cylinder bore located between the cylinder head and cylinder sleeve. The top of the piston extends into this ring at top dead center (T. D. C.) but does not touch it, since the ring has a larger

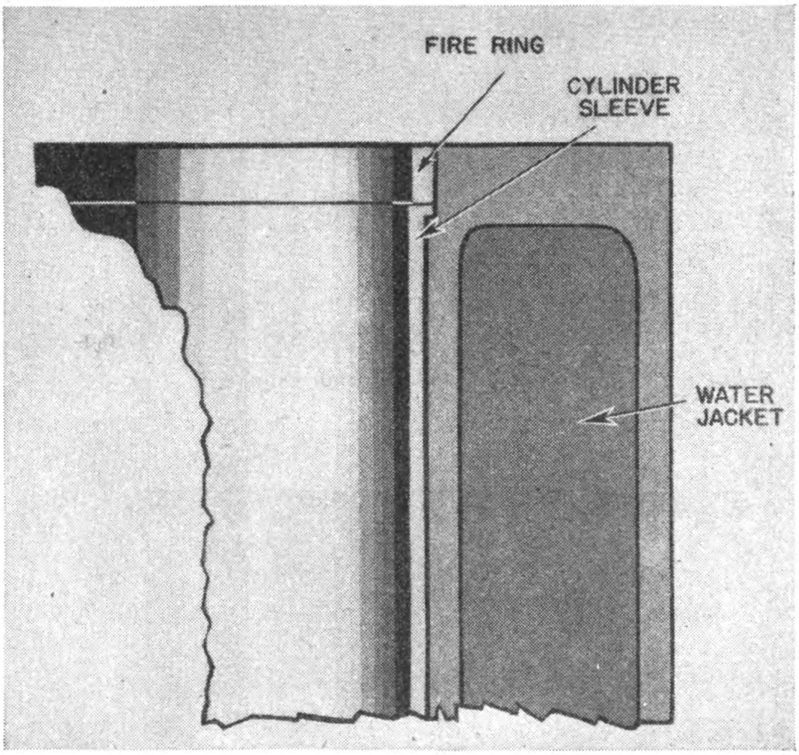



FIGURE 12.—Fire ring.

bore than the sleeve. Thus, the portion of the cylinder which becomes hottest and has the least efficient cooling cannot cause distortion in that portion of the cylinder wall in contact with the piston rings.

*d.* (1) A typical Diesel engine piston assembly is shown in figure 13. The pistons of automotive Diesels follow closely the practices in vogue with gasoline engines. The material generally is cast iron or an aluminum alloy. A solid aluminum alloy piston with an extra long skirt accurately ground the full length and with the top compression ring considerably below the piston head, seems to be favored. Since the piston heads often form part of the combustion

chamber, the top of the piston may be almost any shape depending upon the engine design. It is customary to make Diesel piston heads thicker than those of gasoline engines of the same bore as a means of securing greater heat transfer and more strength. The heat problem is more difficult in two-cycle than four-cycle engines on account of the greater frequency of combustion. Some manufacturers employ a flat insert or disk of high heat conductive alloy screwed on to the top of the piston head in order to dissipate the intense heat of combustion away from the piston head more rapidly.

(2) In most cases Diesel engine pistons are provided with a greater number of piston rings than found on corresponding size gasoline engines. The higher cylinder pressure of Diesels makes it imperative to employ at *least* three compression rings above the piston

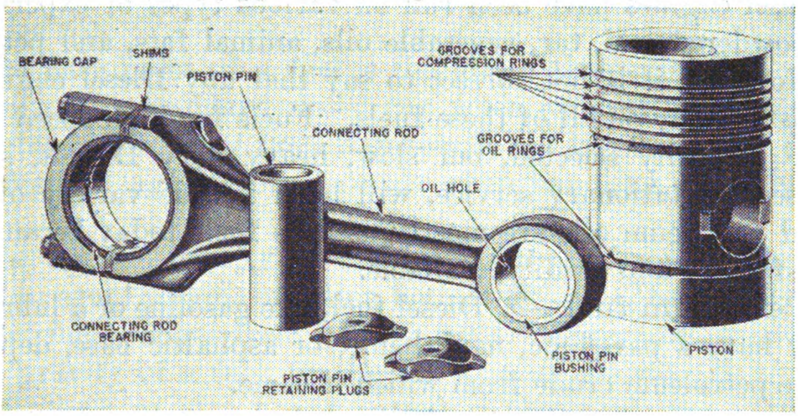



FIGURE 13.—Typical Diesel engine piston assembly.

pin to insure a gastight seal and prevent blow-by. Most automotive Diesel pistons have from four to five rather narrow compression rings and two oil control rings. The top oil ring, above the piston pin, has drain holes through which the cylinder lubricating oil can flow. The bottom oil ring acts as an oil scraper ring.

*e.* Fuel injection units for Diesel engines must be accurately made. The fuel is sprayed into a hot combustion chamber (usually 1,000° F.) at high pressure (anywhere from 1,000 to 20,000 pounds per square inch). This high temperature subjects the injection system to the corrosive action of gases, and the high pressures cause rapid wear of parts. Therefore only the best material and workmanship can be used in the construction of the many parts of the injection system. This is reflected in the cost of the fuel system alone, which is approximately one-fourth the total cost of a Diesel engine. The fuel injection system is a precision mechanism that requires careful maintenance.

SECTION II

## DIESEL FUEL



**9. General.**—*a*. Fuel is a substance composed principally of hydrogen and carbon in such proportions that it will burn readily in the presence of oxygen and liberate heat energy. It may also contain small percentages of such elements as nitrogen and sulphur. The presence of nitrogen is unimportant for the most part, while there is usually a limit to the permissible sulphur content of a fuel because of its corrosive effects.

*b*. Diesel engines have been run on various types of experimental fuels: powdered coal, tar, vegetable oils, animal fats, and petroleum oils. However, it is not correct to say that any Diesel engine will run satisfactorily on all of these fuels. Fuels for high speed Diesels must be carefully selected, but slow, heavy duty Diesels, such as those used in stationary service, will burn a wide variety of fuels. Distilled petroleum oils are mostly used as fuels today because they are satisfactory and readily available.

**10. Petroleum fuel.**—*a*. Diesel fuel, like gasoline or a lubricating oil, may have a paraffinic, naphthenic, or asphaltic base, depending upon the petroleum crude from which it came.

*b*. A representative sample of Diesel fuel contains about 86 percent carbon and about 12 percent hydrogen; this content seldom varies more than plus or minus 2 or 3 percent. In general, the higher the hydrogen value, the more British thermal units (heat energy content) contained in the fuel, and the more nearly it will be of the paraffinic type. This type, because of its good ignition qualities, is generally preferred as a Diesel fuel. However, paraffinic fuels always contain free wax, which affects their flowing qualities (viscosity) at low temperatures. Naphthenic fuels have a cleaning quality and low temperature pour point which is very desirable in automotive Diesel engines.

**11. Physical properties.**—*a*. (1) The general characteristics and properties of Diesel fuels can be divided into those affecting—

(*a*) Handling, storage, and pumping of the fuel *before* it enters the engine cylinder.

(*b*) Ignition and combustion of the fuel *after* injection.

(2) (*a*) Conditions in (1) (*a*) above are chiefly affected by the following qualities:

*1.* Flash point.
*2.* Specific gravity.
*3.* Viscosity and pour point.
*4.* Impurities.

(*b*) Conditions in (1) (*b*) above depend upon—

*1.* Ignition quality.
*2.* Distillation range.
*3.* Chemical composition.
*4.* Carbon residue and asphaltic matter.

(3) It is customary to include a number of these properties in Diesel fuel specifications, although it is impossible to define the merits of a Diesel fuel with any exactness by referring to specification characteristics.

*b.* The flash point of a fuel is the lowest temperature at which it will ignite in a standard closed cup when exposed to a flame. The flash point of all Diesel fuels is generally not less than 150° F. This is a safeguard against fire hazards when handling and storing the fuel.

*c.* The specific gravity of a liquid is the ratio of its weight to that of an equal volume of water, both at 60° F. The specific gravity of Diesel fuels ranges from 0.852 to 0.934. In general, the lower the specific gravity of a fuel, the higher its heat content (B. t. u.), and consequently a greater power output is obtainable per pound from a low specific gravity fuel. Therefore, when changing from one type of fuel to another, it is sometimes necessary to change the fuel injector settings. Specific gravity is used as an indication of the origin of a fuel and as a check on the uniform quality of the supply.

*d.* (1) The viscosity and pour point of a fuel indicate its fluidity. Viscosity is the term used to indicate the internal friction or resistance to flow of a liquid. It is measured in seconds Saybolt, the time required for a measured quantity of liquid fuel at 100° F. to fall through a calibrated hole in a Saybolt Universal Viscometer. The lowest temperature at which fuel oil will just flow (under controlled test conditions) is called the pour point. It indicates the suitability of the fuel for cold weather engine operation, since the fuel must remain fluid in order to be handled by the fuel system. Unless arrangements are made for heating, the fuel must not be more viscous than 550 seconds at the lowest operating temperature, or it will not flow through the fuel system.

326564°—41——2

(2) While maximum viscosity is limited by handling considerations, minimum viscosity is also limited by injection system requirements. The fuel must have sufficient body to lubricate the closely fitted pump and nozzle plungers properly. In order to do this, and prevent wear, scoring, and sticking, the fuel should have a viscosity greater than 35 seconds at 100° F. The fuel must also be viscous enough to prevent leakage at the pump plungers and "dribbling" at the injection nozzle. Leakage occurs when the fuel viscosity is less than 34 or 38 seconds at 100° F. depending upon the type, temperature, and pressure of the injection system.

*e.* Fuel shipped from a refinery is usually free from water and sediment. Diesel fuel, being more viscous than gasoline, will hold dirt in suspension longer. As it is transferred from tank to tank from the refinery to the engine, it will sometimes pick up sufficient water and sediment to corrode the fuel pump parts or injection system parts. To prevent this, care must be exercised in handling fuel and line fuel strainers must be checked frequently.

*f.* The ignition quality of a Diesel fuel is its ability to ignite spontaneously (without mechanical assistance such as a spark) under the conditions existing in the engine cylinder. A fuel with a good ignition quality (one that will ignite at low temperatures) is most desirable for Diesel engines for several reasons. Smoking, knocking, and ease of starting are somewhat dependent on the ignition quality of the fuel. An engine will start if, after compression, the temperature in the engine cylinder is above the ignition temperature of the fuel. Compression temperature is related to outside air temperature, so the lower the ignition temperature of the fuel, the lower the possible atmospheric temperature at which the engine will start. If the ignition temperature of a fuel is too high, the engine will smoke, particularly at light loads when the engine temperatures are low.

(1) Combustion knock (detonation) in a Diesel is thought to be due to the too rapid burning of the fuel charge that accumulates in the engine cylinder between the beginning of injection and ignition. In a Diesel engine the mixing of compressed air and fuel must take place very rapidly. Hence, if the fuel has the characteristic of being difficult to ignite, the mixing will be nearly complete before ignition takes place and so it will suddenly ignite and produce an excessive pressure rise which results in detonation. A fuel having good ignition qualities will ignite and start to burn at the very beginning of injection and before all the fuel hits the air. It will continue to burn progressively as it is injected into the cylinder and thus avoid detonation.

(2) The ignition quality of Diesel fuels is indicated by cetane numbers, just as octane numbers are used to indicate the antiknock quality of gasoline. The ignition quality of a Diesel fuel is determined by comparing it with a standard reference fuel. A mixture of cetane, which has good ignition qualities, and alpha-methyl-naphthalene, which has poor ignition qualities, is used to establish a standard of measurement. The cetane number of a fuel is the percentage of cetane that must be mixed with alpha-methyl-naphthalene in order to duplicate the ignition quality of the Diesel fuel being tested. Thus, if a fuel has the same ignition quality as a reference fuel composed of 60 parts cetane and 40 parts alpha-methyl-naphthalene, the fuel has a cetane number of 60. The ignition quality most suited for any particular engine is best determined by trial and is usually recommended by the engine manufacturer.

*g.* Distillation range means boiling range, and indicates the volatility of a fuel. The end point is the temperature at which the liquid fuel is completely evaporated. It is customary in specifications to give the temperature at which 90 percent of the fuel will evaporate. Diesel fuels are not as volatile as gasoline, and are therefore safer to handle. The volatility of high speed Diesel fuels should not be higher than is necessary to assure clean burning, since highly volatile fuels have a low B. t. u. content.

*h.* (1) The carbon residue test determines the amount of carbon remaining after the volatile portion of a fuel has been evaporated. This test gives an indication of the amount of carbon that may be deposited within the combustion chamber. The amount of carbon residue should be low, because it affects heat conductivity, and may clog the injection nozzles.

(2) The ash content is determined by burning a known weight of oil and weighing the ash remaining. The ash usually contains such impurities as sand and rust which are extremely abrasive, and the ash content must therefore be low to prevent excessive wear.

*i.* An excessive amount of sulphur, regardless of its form, is undesirable when there is water in the crankcase. After combustion, the sulphur in a fuel may reach the crankcase, unite with the water, and form sulphuric acid which will attack bearings, shafts, and cylinder walls. Therefore, when operating engines in cold weather or intermittently in any temperature, avoid the use of fuels high in sulphur content, because water is most apt to accumulate in the crankcase during these types of operation. A standard method of determining the corrosive tendency of a fuel is to immerse a copper strip

for 3 hours in the fuel at 212° F., and note the discoloration. A slight discoloration is acceptable.

*j.* A copy of the current Navy Specifications covering the type of Diesel engine fuel oil desired should be consulted when ordering or checking Diesel fuel oil.

## SECTION III

## DIESEL IGNITION SYSTEMS



**12. General.**—Diesel engines are generally classified by ignition systems, which are of three types:

*a.* Spark ignition (semi-Diesel engine).

*b.* Surface ignition (hot bulb engine).

*c.* Full compression ignition (true Diesel engine).

**13. Spark.**—The spark ignition system, developed by a Swedish engineer, K. J. E. Hesselman, depends upon an electric spark for ignition, much the same as the conventional gasoline engine. It is often referred to as the semi-Diesel engine. Its similarity to the Diesel engine lies in the fact that pure air is compressed and the fuel injected at the end of the compression stroke as it is in Diesel engines. The use of a spark for ignition permits considerably lower compression pressures because the heat of compression is not depended upon for ignition. With combustion pressures as low as 125 to 150 pounds per square inch, piston and bearing pressures are also lower, so that these parts can be built of lighter materials. The advantages of a Hesselman type Diesel engine are that it—

*a.* Eliminates gasoline, and consequently reduces the fire hazard.

*b.* Reduces the cost of operation because it uses a fuel cheaper than gasoline.

*c.* Is lighter and costs less to build than a full Diesel engine.

*d.* Is easier to start.

A cross section view of a Hesselman type engine is shown in figure 14.

**14. Surface.**—Because an engine using surface ignition is a cross between the gasoline and Diesel engine, it is sometimes incorrectly called a semi-Diesel; a more practical definition is the hot bulb engine. It operates in the medium compression range with pressures of approximately 250 pounds per square inch and depends upon a hot

surface, or hot plate, to provide the necessary heat to ignite the fuel. In the hot bulb engine, the compression space is a bulb-like chamber

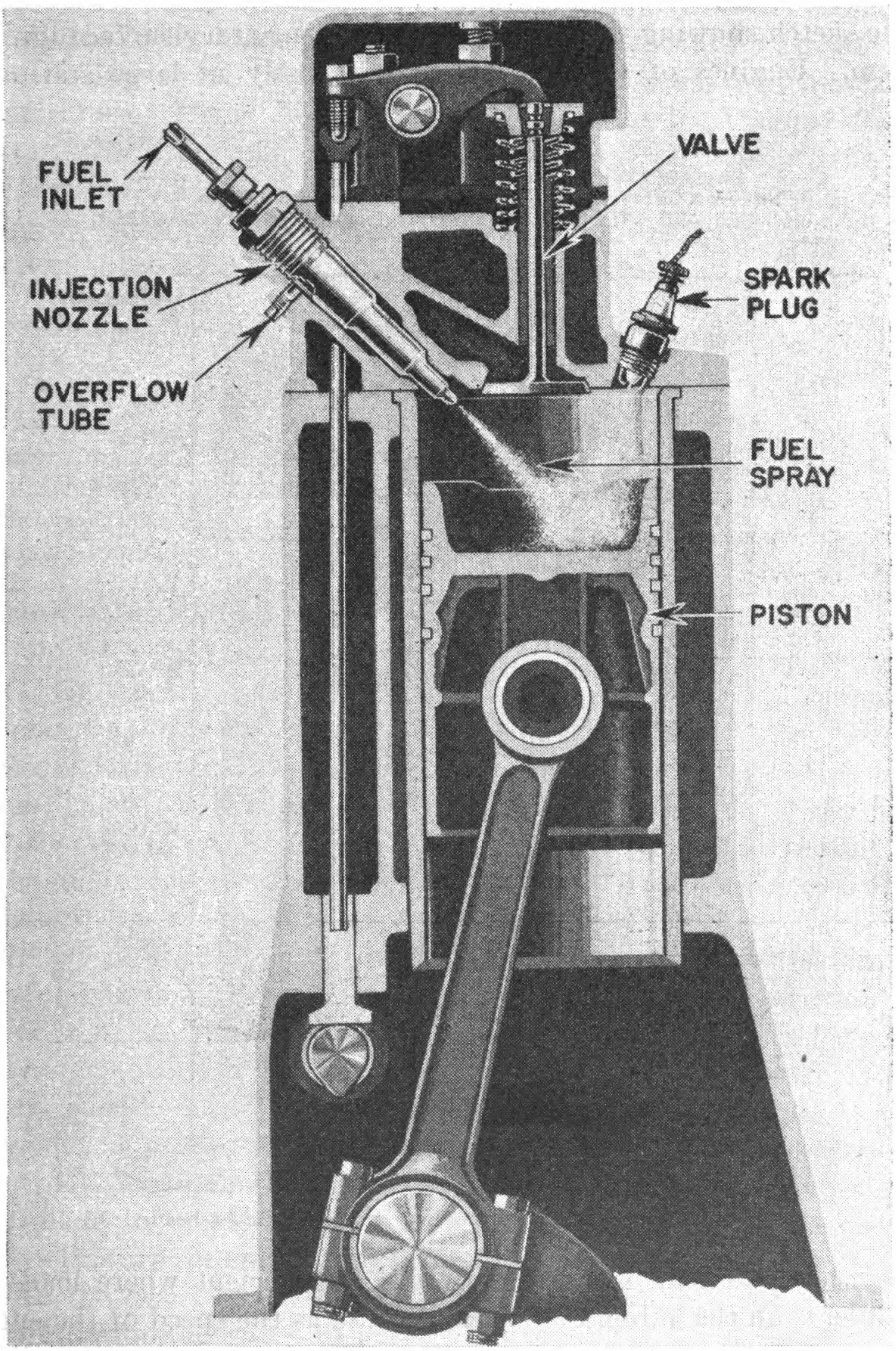



FIGURE 14.—Cross section view of Hesselman type engine showing fuel injection nozzle and spark plug.

cast in the cylinder head, which communicates with the cylinder through a passage of considerable area. The wall of the bulb is

either partly water-cooled or not cooled at all. It is thus kept hot enough by the combustion process to ignite the injected fuel. Fuel is injected directly into the hot bulb chamber. Figure 15 is a diagrammatic sketch showing the principles of an elementary surface ignition system. Engines of this type are used mostly in large stationary

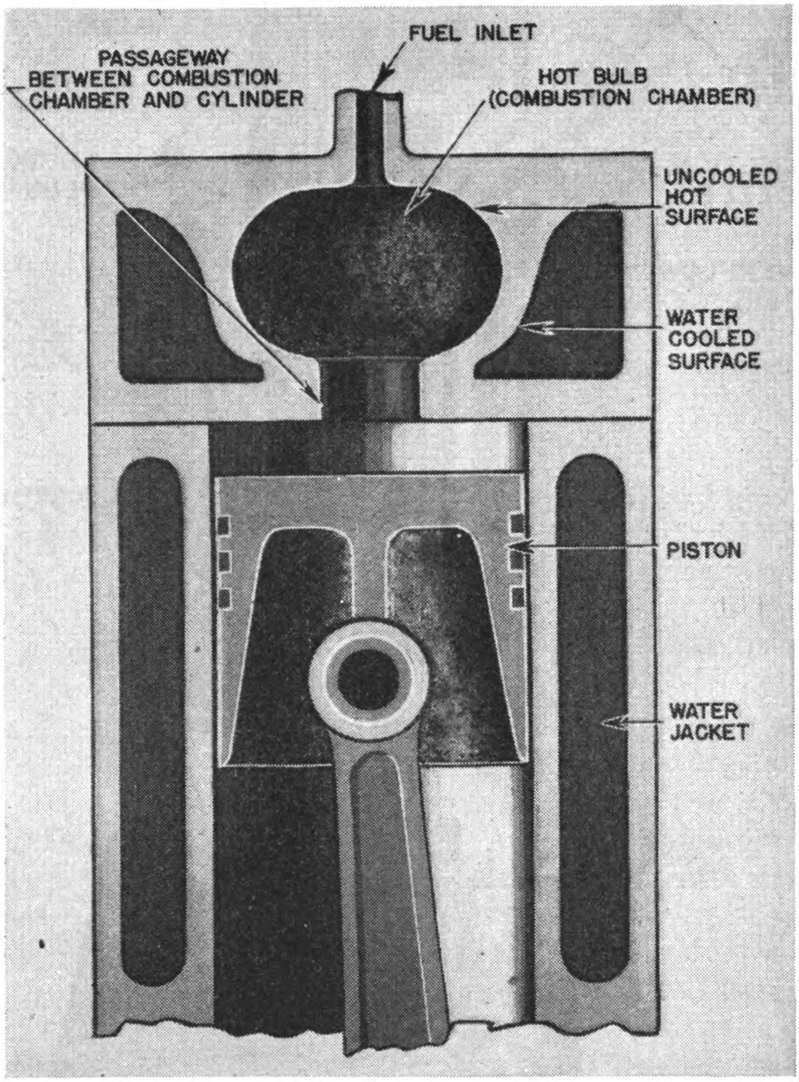



FIGURE 15.—Diagram of surface ignition cylinder head.

units where the load is constant. It is not efficient where loads are variable, as in the automotive field, because as the speed of the engine decreases the hot bulb may cool to such an extent that it will not ignite the fuel, or the temperature in the various cylinders may be different, thus causing roughness in operation. At high speeds the bulb has a tendency to overheat.

**15. Compression.**—In this system the fuel is ignited entirely by the heat of compression. It is used on the full Diesel engine which operates with high compression pressures of approximately 500 pounds per square inch. An elementary law of physics states that, all other things being equal, increasing the pressure of a gas will increase its temperature. Hence, in this type of engine at the time of fuel injection, the air is, figuratively speaking, red hot due to the high compression. This hot air causes the finely sprayed particles of fuel to ignite almost instantly when they come in contact with it. From this action, the term compression ignition is derived.

## Section IV

## COMBUSTION CHAMBER



**16. General.**—Diesel fuel must be injected into the combustion chamber near the top of the compression stroke. It must be *thoroughly* mixed with the compressed air (atomized) and distributed as *evenly* as possible throughout the chamber. None of the liquid fuel should strike the cylinder walls. Therefore it is essential that the shape of the combustion chamber and the characteristics of the injected fuel spray be closely related.

**17. Open combustion.**—*a.* The open combustion is the simplest form of combustion chamber. It is a cavity above the piston that has no special cells, pockets, or passages. The fuel is injected directly into the clearance volume at the top of the cylinder. If both the cylinder head and piston head were flat or pancake-shaped, the air would be only slightly agitated and the fuel would be poorly distributed. Consequently, deviations from strictly flat shapes have been made to create air movement. Two of the methods used to achieve this are the entrance swirl and the piston swirl.

*b.* In the *entrance swirl*, a deflector lug, or plate, is placed on one side of the intake valve to give the incoming air a circular motion which continues during the compression stroke. Figure 16 shows a typical deflector lug installation.

*c.* The *piston swirl* method employs a piston that has a circular depression in the head, as shown in figure 17. As the piston ap-

proaches the end of its compression stroke, fuel is injected toward the center of the piston head, which causes the air to swirl or tumble.

**18. Turbulence.**—*a.* A turbulence chamber (fig. 18) is now used to agitate the air more thoroughly than the open type already mentioned. There is no clearance space between the piston and the cylinder head except that necessary to prevent the piston striking the head, so that practically all the air between the piston head and cylinder head is forced into the turbulence chamber during the compression stroke. Several manufacturers place the turbulence chamber in the cylinder head while others place it at the upper portion of the

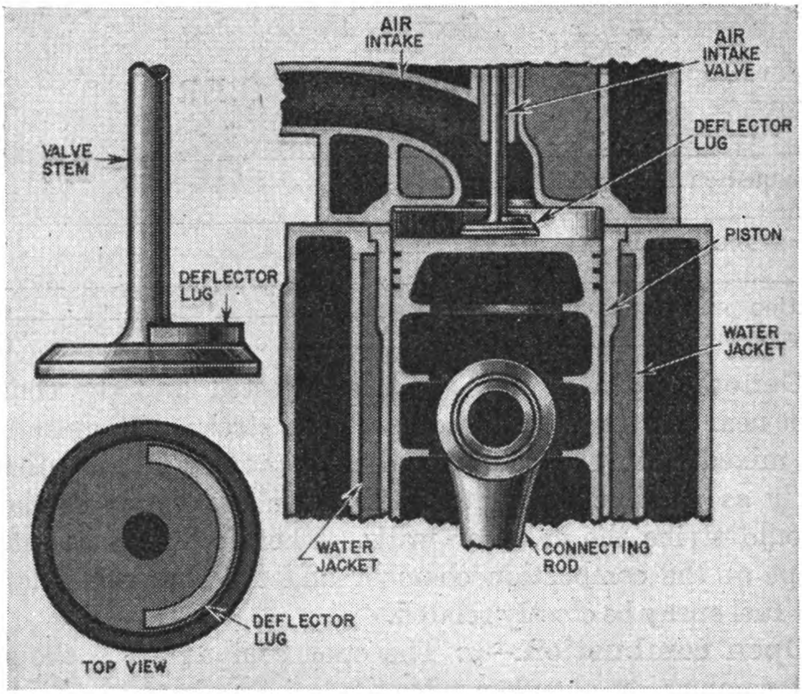



FIGURE 16.—Lug on intake valve to deflect air stream.

cylinder casting and to one side of the cylinder. In all turbulence chambers the position of the spray valve (injection nozzle) is of greatest importance. If the fuel spray is not directed toward the throat connecting the chamber with the cylinder, combustion will be incomplete and the engine will fail to develop its full power.

*b.* Figure 18 illustrates a typical turbulence chamber in the cylinder head. By the time the piston reaches top dead center, 80 percent of the confined air has been compressed in the turbulence chamber. This action, as shown in figure 19, circulates the air at a high velocity, and when the fuel spray is injected the velocity of the air passing

across the stream of oil insures thorough mixing. The glow plug shown is used only to warm the chambers in cold weather.

*c.* Figure 20 is a typical example of a turbulence chamber located at the top and to the side of the cylinder. It is seen that the fuel injection nozzle is located at the side of the chamber opposite the passage from the cylinder.

*d.* The air velocity depends on the piston speed and the size of the opening through which the air must pass; the larger the opening,

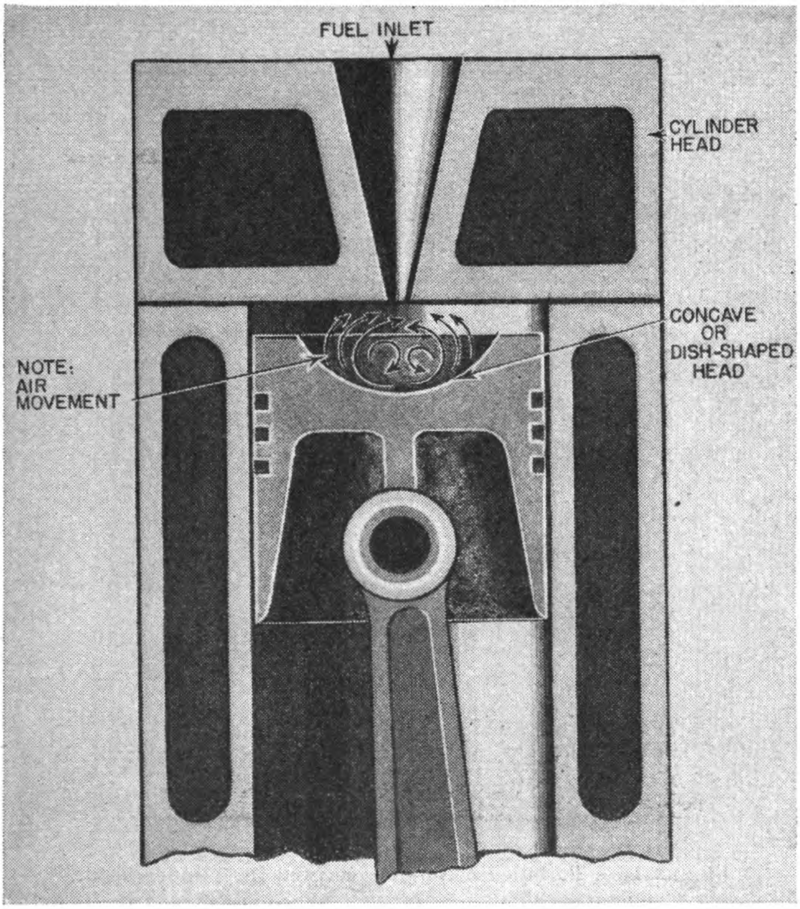



FIGURE 17.—Dish-shaped piston head swirls air.

the slower the velocity of the air passing through it, and the smaller the opening, the greater the air velocity. Air revolves inside the turbulence chamber at about 50 times crankshaft speed during ignition and combustion. This gives more complete combustion at a more constant rate, resulting in maximum smooth power with minimum fuel consumption, smoke, and noise.

**19. Precombustion.**—*a.* The precombustion chamber (fig. 21) is somewhat similar to the turbulence chamber in that it is an auxiliary

cavity. However, its function is different. As the piston completes its compression stroke, about 35 percent of the cylinder charge of air is forced into the precombustion chamber, while the remaining air stays in the space over the piston. When the fuel is sprayed into the precombustion chamber there is not enough air present to support complete combustion, and only part of the charge is ignited.

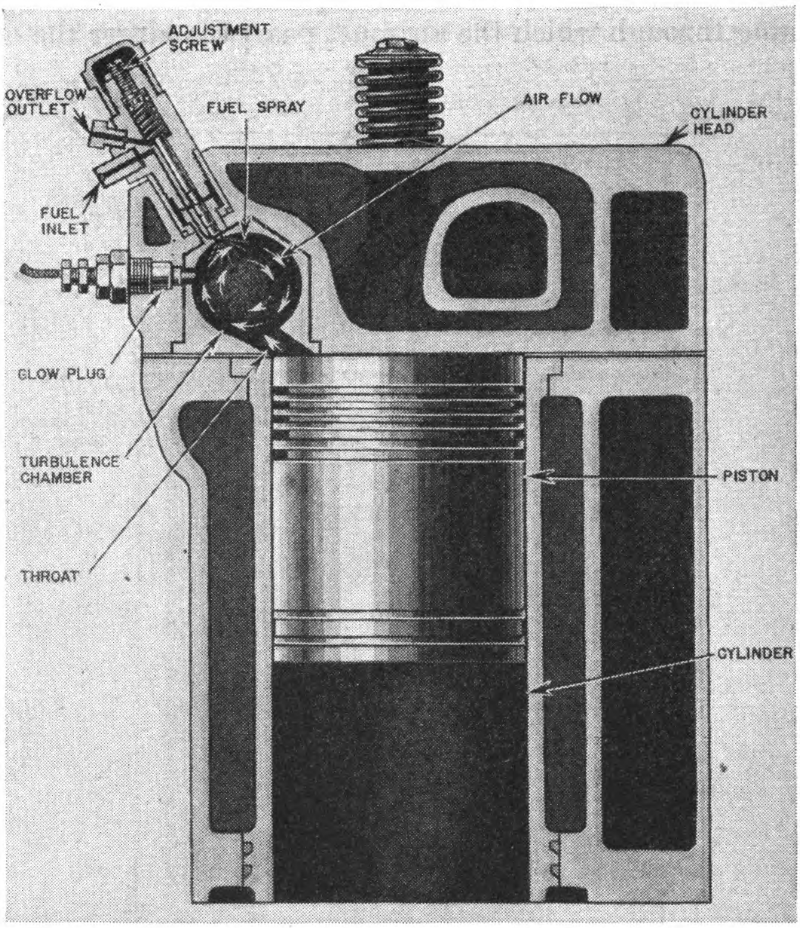



FIGURE 18.—Turbulence chamber located in cylinder head.

The increased pressure in the chamber, due to the partial combustion, forces the gases and vaporized fuel out into the cylinder space where the gaseous mixture mixes with the hot air, and combustion is completed. Usually the throat connecting the precombustion chamber and the cylinder is not a free opening but rather a number of small holes. The size of these holes prevents drops of fuel spray from entering the cylinder. The compressed air from the cylinder is, however, permitted to pass through and vaporize the fuel.

*b*. Fuel injection pressures in a precombustion chamber need not be as high as in the turbulence type chamber because a coarser spray is satisfactory. At first, precombustion chambers were located centrally in the cylinder head between the intake and exhaust valves but since this location restricted the size of valves that could be

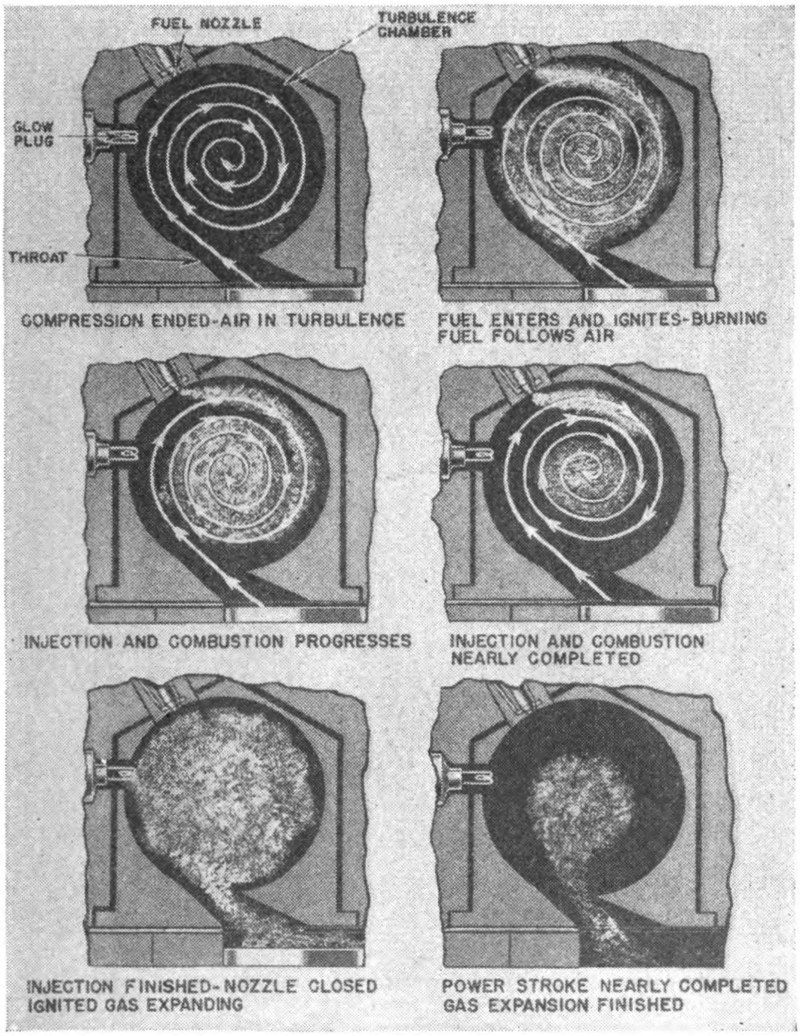



FIGURE 19.—Action within turbulence chamber.

used, the arrangement was discarded. In present designs the precombustion chamber is located in one side of the cylinder head.

*c*. Figure 21 shows a precombustion chamber mounted parallel to and above the cylinder. Figure 22 is an example of the precombustion chamber at an angle to the cylinder. These precombustion chambers, sometimes called cups, are used in industrial tractors and are built as individual units screwed into the cylinder head.

**20. Air.**—*a.* In an air chamber engine, part of the compression cavity is a chamber separated by a throat from the space directly above the piston. The fuel injection nozzle is located *outside* this air chamber, which distinguishes this design from either the precombustion chamber or turbulence chamber type. The fuel injected does not pass through the auxiliary chamber.

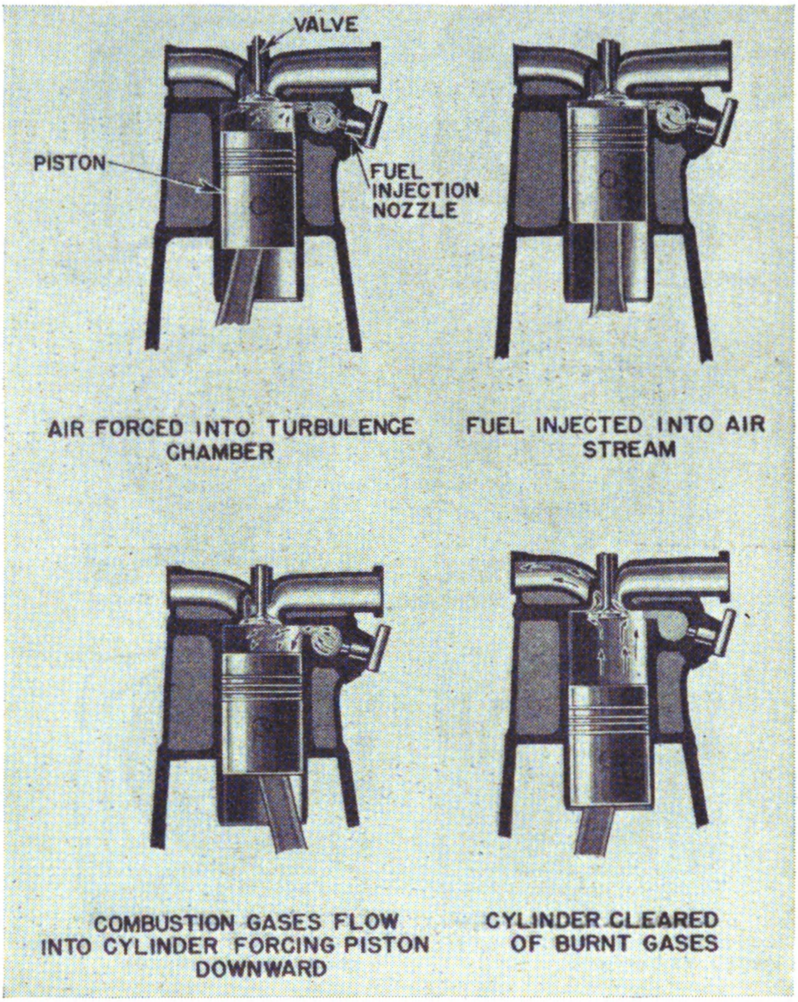



FIGURE 20.—Action with turbulence chamber located at side of cylinder.

*b.* A typical example of an air chamber in a cylinder head is shown in figure 23. The combustion chamber is conical, conforming to the shape of the fuel spray. The piston head is slightly dished and comes close to the cylinder head at the end of the compression stroke. The air chamber is located alongside the combustion chamber and discharges through a small throat. All the air that escapes through this throat mingles with the rich fuel mixture formed in

the combustion chamber. Air is compressed in both the combustion chamber and the air chamber. When fuel injection begins, the conical fuel stream mixes with the hot compressed air in the combustion chamber and partial combustion occurs. This increases the pressure in the combustion chamber and prevents the air trapped in the air chamber from escaping. As the piston is forced down by the expansion of the burned gases, the combustion chamber pres-

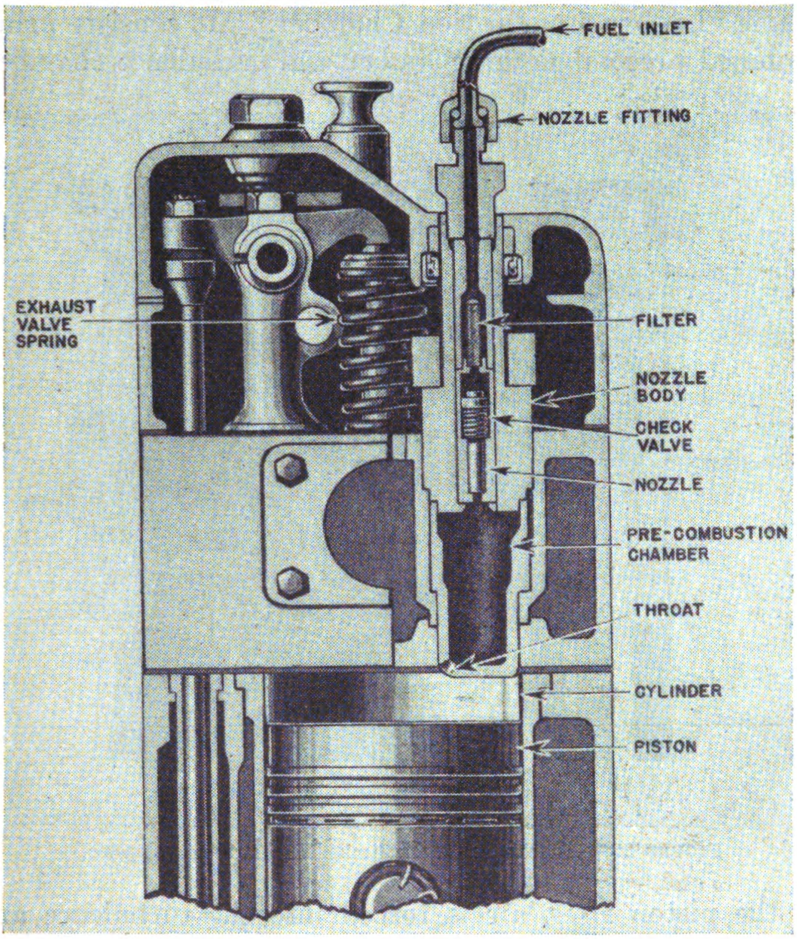



FIGURE 21.—Precombustion chamber parallel to and above cylinder.

sure drops. This allows the air to flow from the air chamber through the throat into the partially burned fuel, creating a turbulence and supplying additional oxygen to complete the combustion.

*c.* Figure 24 shows how the air chamber may be placed in the piston head. It operates similarly to the one described above.

*d.* From the above discussion, it is apparent that the air chamber stores compressed air near the combustion chamber and releases it at

a uniform rate throughout the combustion process by balancing the air pressures in the cylinder and air chamber. It overcomes the difficulty of providing sufficient oxygen to support complete combustion toward the end of the power stroke. This gives a controlled rate of combustion and consequently smooth development of maximum power.

**21. Combination precombustion and turbulence.**—*a.* This type of combustion system (fig. 25) is probably better known by the trade name "Lanova Combustion Chamber." It consists principally of a combined precombustion chamber and turbulence chamber.

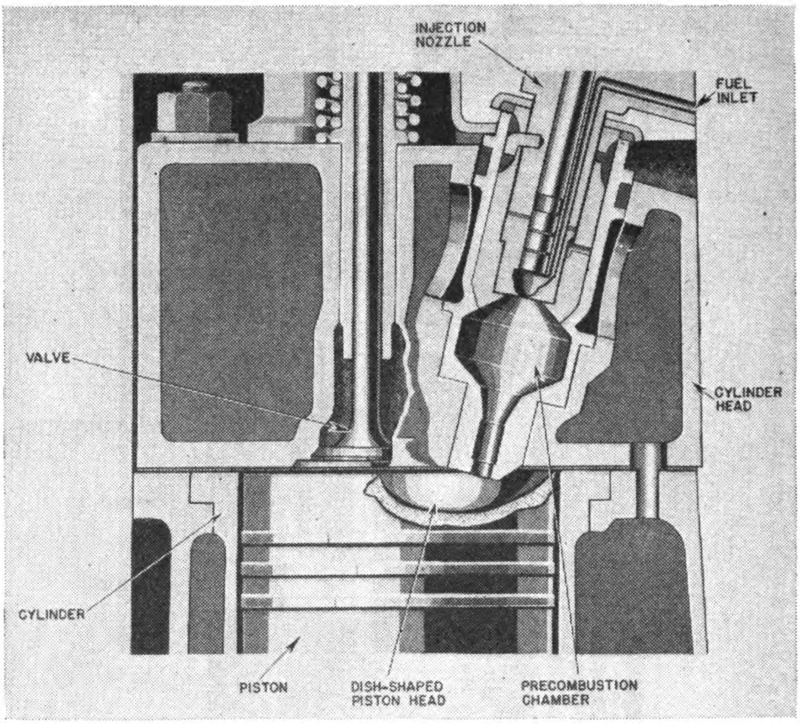



FIGURE 22.—Precombustion chamber at angle to cylinder.

*b.* As the piston rises, air is forced into the turbulence and precombustion chambers where it is highly compressed. Near the end of the compression stroke fuel is injected in a fan-like spray toward the throat connecting the precombustion chamber with the turbulence chamber. A *small* portion of the fuel strikes the hot walls of the turbulence chambers and is immediately vaporized and ignited. The *greater* portion of the fuel stream is directed into the throat of the precombustion chamber. There is now an excess of fuel in the throat and only partial combustion can occur at this point. The increased pressure in the precombustion chamber, resulting from the expansion of the partially burned fuel vapor, forces the vapor back into the

fuel spray. As the fuel spray and expanding gas stream meet, each deflects the other into paths around the circular walls. The turbulence thus created and the excess of air in the cavities thoroughly mixes the fuel and air and produces combustion. As the piston is forced down by the expanding gas the pressure within the cylinder drops below that of the air trapped in the precombustion chamber

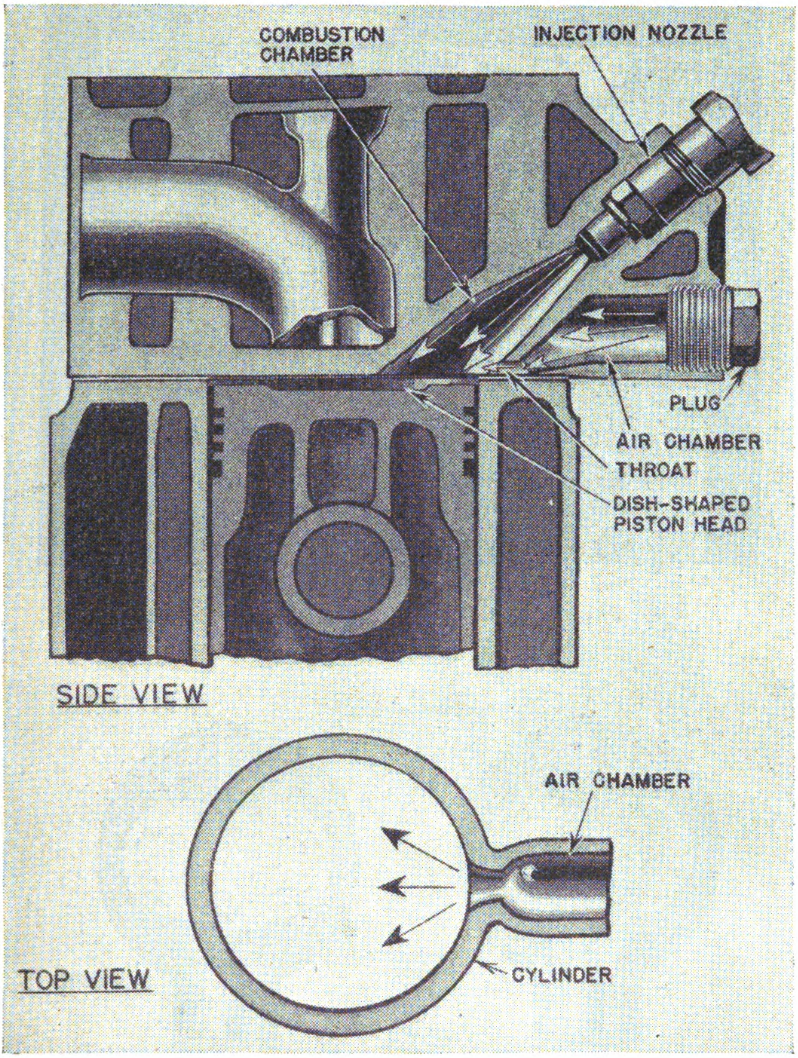



FIGURE 23.—Air chamber in cylinder head.

and the air begins to flow out. This supplies the fuel spray with the additional heated air necessary to support continuous combustion until the power stroke is completed.

*c.* Cylinder pressures rise uniformly and smooth power independent of engine speed is produced by this system, because the fuel and air are thoroughly mixed. But at the same time, the rate of com-

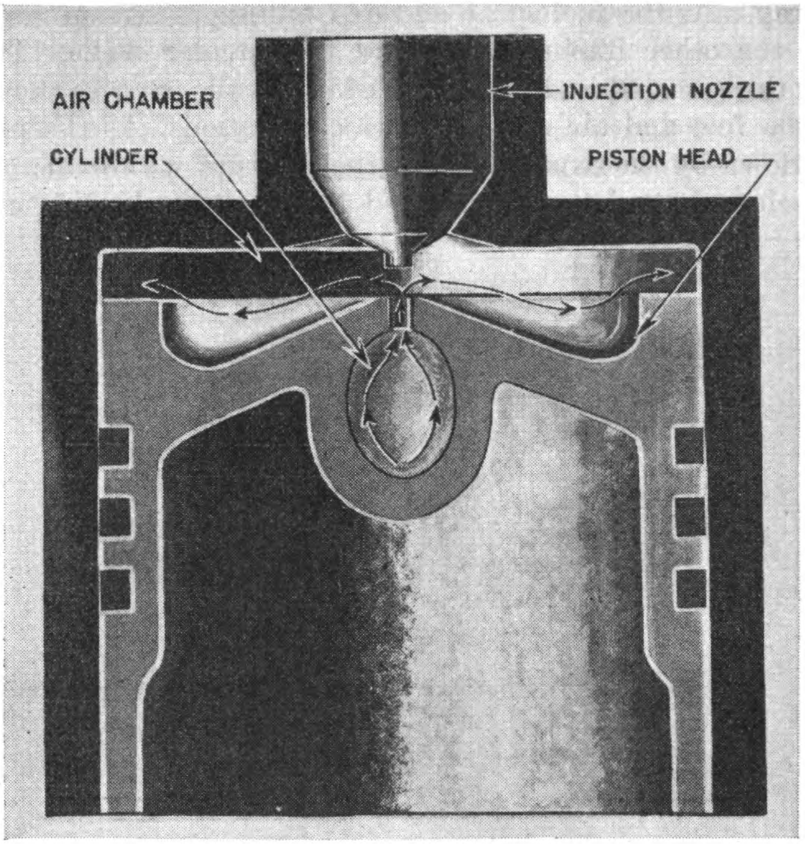



FIGURE 24.—Air cell in piston head.

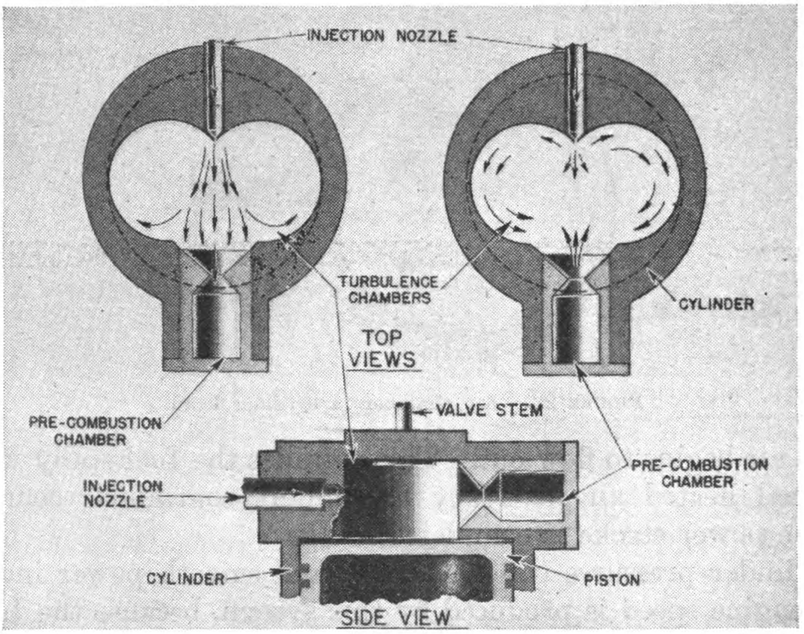



FIGURE 25.—Combination precombustion and turbulence chamber.

bustion is controlled by regulating the air supply available through a balancing of pressures.

**22. Split precombustion.**—*a.* A more recent application of the combination combustion chamber system goes a step further by separating the precombustion chamber into two chambers called inner and outer cells. These two cells are connected by a venturi or funnel-shaped passage. The inner cell in turn is connected by a venturi

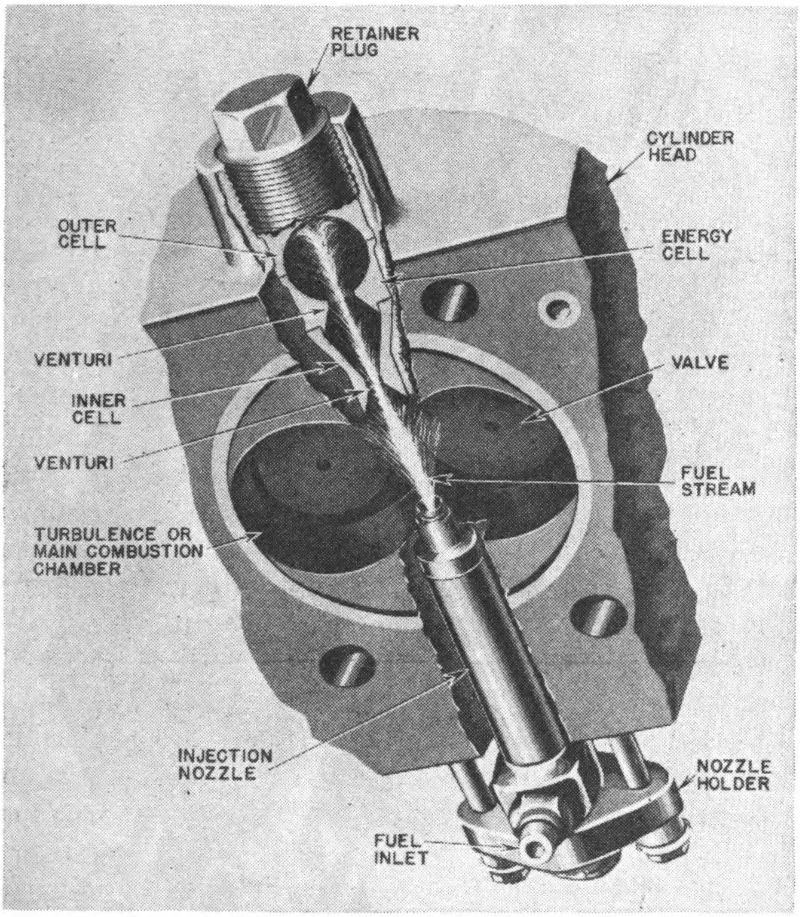



FIGURE 26.—Fuel entering precombustion chamber.

to the turbulence chamber. Figures 26 and 27 help to illustrate this type of construction.

*b.* During the compression stroke about 10 percent of the total compressed air passes into the precombustion chamber (called "energy cell" by its manufacturer), while the balance of the air remains in the turbulence (or main combustion) chamber. The fuel, most of which penetrates into the precombustion chamber, is injected in the form of a pencil stream across the narrow throat of the combustion chamber.

Only a small portion of the boundary layer of the fuel stream follows the curve of the turbulence chamber and swirls in two opposite directions within it. Most of the fuel entering the precombustion chamber is trapped in the small inner cell, but a small amount passes through into the outer cell where it meets a sufficient quantity of

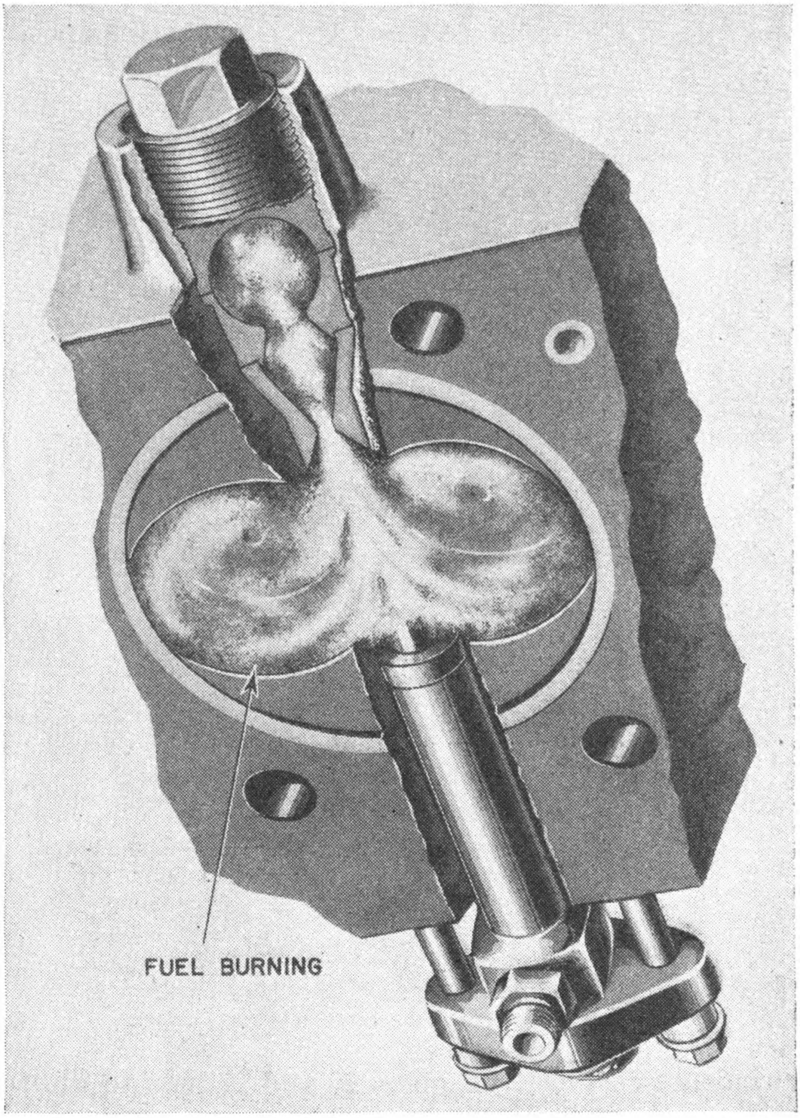



FIGURE 27.—Fuel burning in precombustion and turbulence chambers.

superheated air to ignite instantaneously. This instantaneous combustion rapidly raises the pressure within the precombustion chamber and forces the fuel accumulated in the inner cell back into the main combustion chamber containing the main body of compressed air. Here, owing to the shape of the chamber, turbulence is pro-

duced and the fuel burns continuously as it issues from the precombustion chamber. Owing to the restriction of the two venturis connecting the precombustion chamber, the blowback of the fuel into the combustion chamber is controlled, so that this operation consumes an appreciable period of time thus producing a prolonged and smooth combustion in which the rate of pressure rise on the piston is gradual and the maximum pressure comparatively low for a Diesel.

## SECTION V

## FUEL INJECTION NOZZLE



**23. General.**—*a*. The fuel injection nozzle forces a spray or jet of fuel into the engine cylinder in a form that will readily ignite. The type of nozzle employed on a Diesel engine depends largely upon the type of combustion chamber used. The nozzles in open combustion chambers, which lack turbulence and into which the fuel is injected directly, must discharge the fuel in several fine streams so that it will vaporize and ignite rapidly. This requires holes of such minute size that fuel will flow through them only when backed by exceedingly high pressure. On the other hand, combustion systems with ample turbulence will satisfactorily atomize coarser fuel streams backed by lower pressure issuing from larger holes. Nozzles are designed to deliver a fuel spray that conforms as far as practicable to the shape of the combustion chamber so that the fuel particles will be well distributed in the combustion chamber and thoroughly mixed with the compressed air. Several possible locations of nozzles with respect to the engine cylinder axis are shown in figure 28.

*b*. (1) Injection nozzles are removable individual units secured to finished surfaces on the engine cylinder head by a yoke and hold down studs. They consist essentially of three main parts:

(*a*) The nozzle tip, containing the orifice or jet that directs the fuel stream into the combustion chamber.

(*b*) The body, which houses the component parts.

(*c*) The holder, which secures the injection nozzle unit to the cylinder head.

(2) Nozzle parts are made of hardened steel, ground or lapped together to provide the accurate fits necessary between operating parts to prevent fuel leakage at high pressures, which in some types of fuel nozzles reach 20,000 pounds per square inch. In some designs the nozzle tip projects slightly into the main combustion chamber where it is exposed to the high temperature of combustion. The operating parts are lubricated by the fuel oil itself.

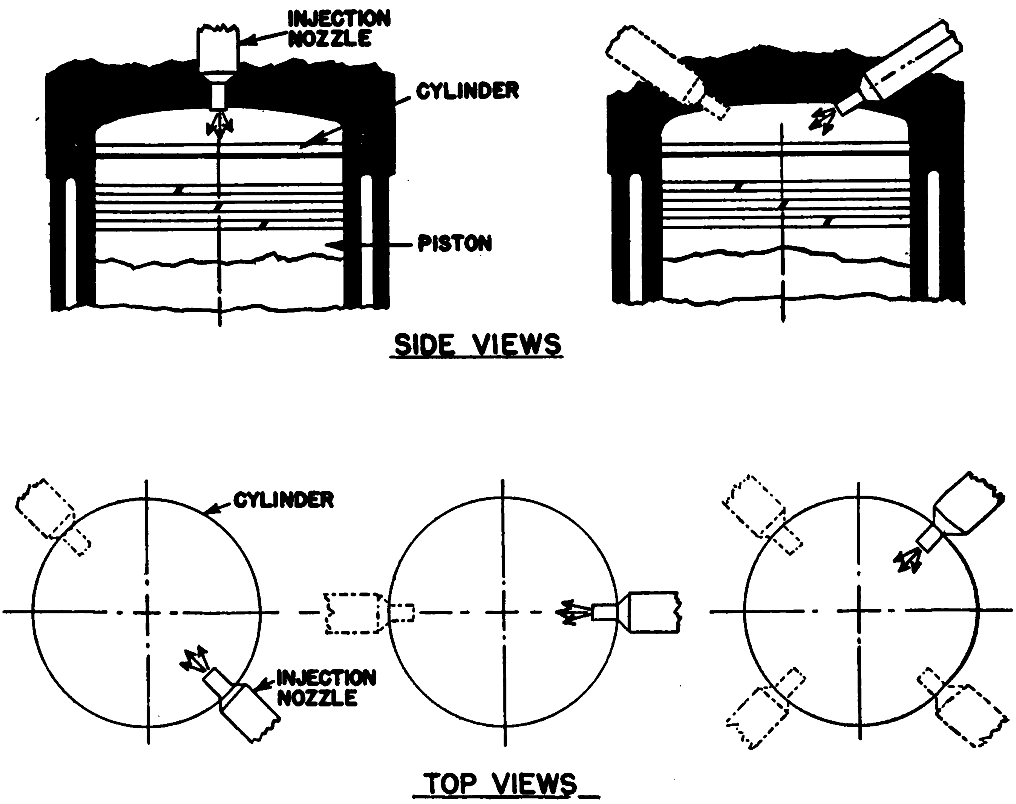



FIGURE 28.—Injection nozzle locations.

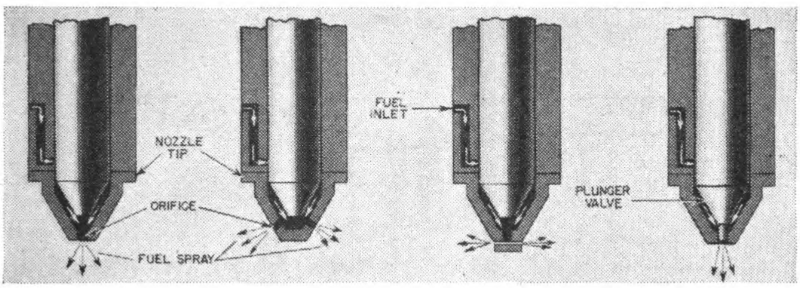
**24. Classification of nozzle tip.**—*a.* The orifice (hole) in the nozzle tip directs the spray of fuel into the combustion chamber. Nozzle tips may be classified as—

(1) Single hole.
(2) Multiple hole.
(3) Circumferential.
(4) Pin or pintle.

These various types are shown in figure 29.

*b.* The size and position of the single hole nozzle tip imparts various characteristics to the fuel stream, as shown in figure 29①. It is obvious that with a high injection pressure and a small diameter hole

the fuel stream will be narrow and have a high velocity. This will not only cause the fuel to penetrate through the compressed air in the combustion chamber but may also cause the liquid fuel to strike the comparatively cool cylinder walls, making complete fuel vaporization difficult. If the hole is large and the injection pressure low, there will be an over rich fuel air mixture near the nozzle tip and a lean mixture at a distance from it. This results in incomplete combustion, forms carbon on the nozzle tip, and clogs the small nozzle holes. In some injection nozzles the orifice is at an angle to the axis of the nozzle, so that the fuel stream is injected into the compressed air at an angle, producing a turbulent effect. In some instances turbulence is obtained by fluted or spirally grooved holes, which give a twirling motion to the fuel stream as it enters the combustion chamber. Extreme care is exercised by the designer in selecting the nozzle for his engine design.




① Single hole. ② Multiple hole. ③ Circumferential. ④ Pintle.

FIGURE 29.—Types of nozzle orifices.

*c.* Multiple hole nozzles have more than one hole, as illustrated in figure 29②. These several holes split the injected fuel into different streams and distribute the fuel better in the combustion chamber.

*d.* The circumferential orifice (fig. 29③) has a disk placed beneath a single hole orifice. It breaks the fuel stream into a thin flat sheet and thus distributes the highly atomized fuel to all parts of the cylinder.

*e.* The pin or pintle orifice is the most commonly used. Figure 29④ shows the plunger valve fitted with a pin-shaped shank that extends through the orifice hole. Pintle nozzles may be designed to produce various angles in the spray cone. The pin of the pintle nozzle is forced through the orifice after each injection period. This action prevents the hole from clogging and insures free passage of fuel at all times.

**25. Classification of nozzle.**—The nozzle itself may either be of the open or closed type. An open nozzle does not control the flow

of fuel. A nozzle is termed closed if it contains a spring-loaded metering valve near or at its orifice. In the open type, fuel injection is controlled by the fuel pump, while in the closed type it is controlled by the spring-loaded valve which is actuated by a cam, hydraulically by the fuel pressure, or magnetically by an electrical circuit.

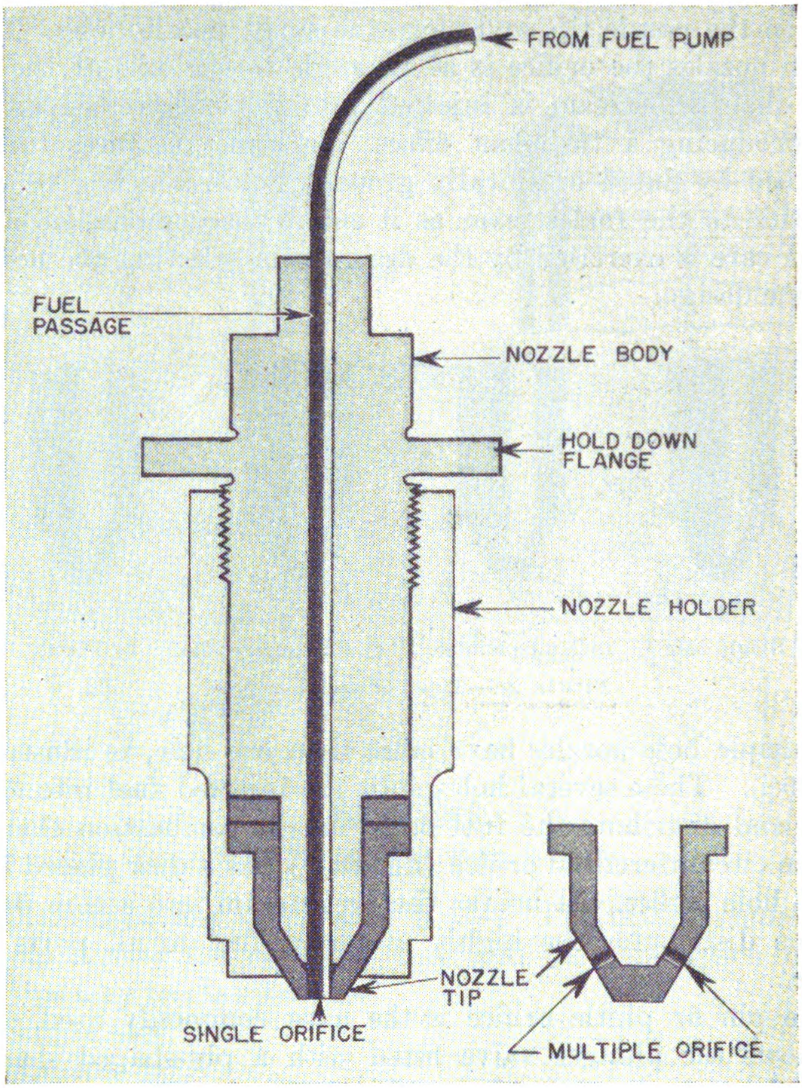



FIGURE 30.—Open nozzle.

**26. Open nozzle.**—*a.* Except for ball check valves (fig. 30) preventing a back flow of the combustion gases, there is a continuous, open fuel passage between the fuel pump and the combustion chamber in the open type nozzle. The fuel pump injects and times the fuel through the nozzle tip at the correct moment. Fuel injection begins

when the fuel pump raises the pressure sufficiently to unseat the check valves and ends when the fuel pressure drops below the combustion

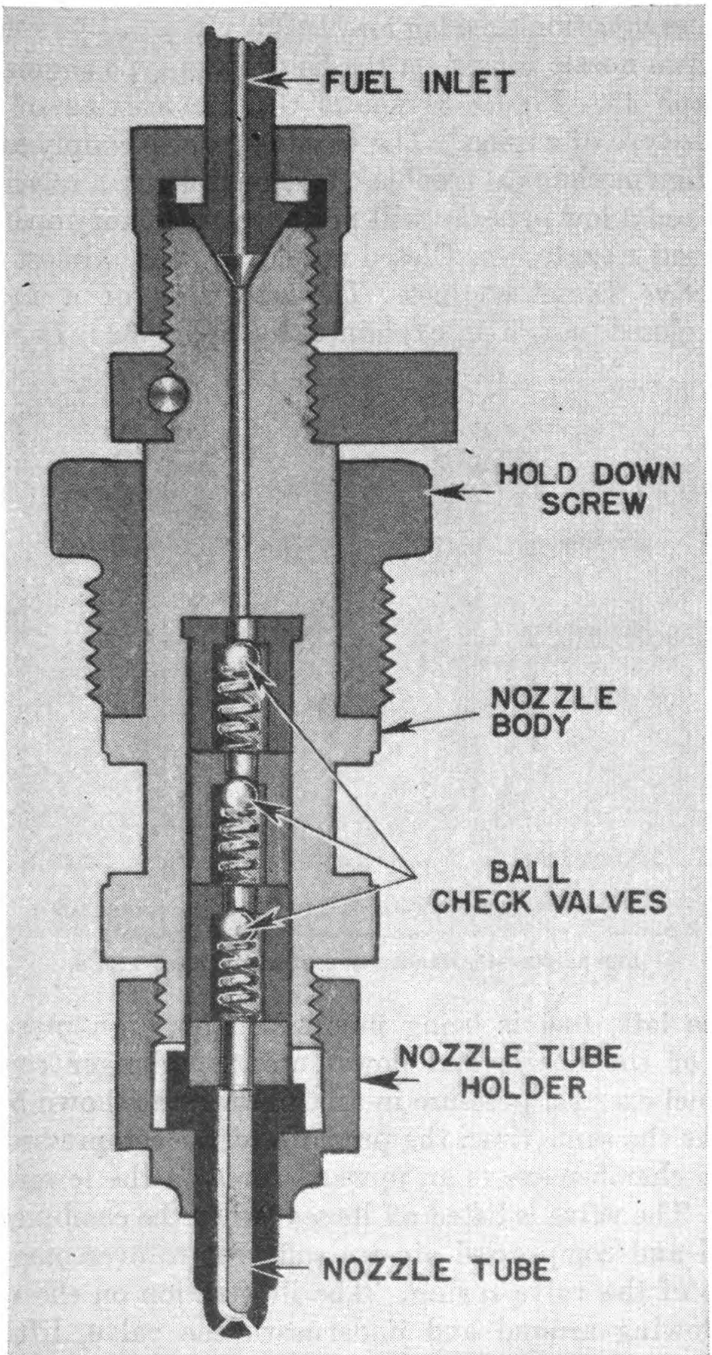



FIGURE 31.—Open nozzle for Hesselman type engine.

chamber pressure. Thus, the pressure and velocity of the fuel stream is low at the beginning and end of injection, resulting in poor atomi-

zation and penetration. Fuel particles may "dribble" and cling or drip from the nozzle tip, thus clogging the orifices. Fuel oil is compressible at high pressures, and since the fuel passage is sometimes quite long, an injection time lag may occur.

*b.* The open nozzle is used on the Hesselman type engines discussed in paragraph 13. Figure 31 shows the construction of the nozzle used on this type of engine. The nozzle operates simply and is therefore free from mechanical trouble. It is used where a relatively coarse fuel spray and a low pressure will produce satisfactory operation.

**27. Closed nozzle.**—*a.* Closed nozzles are used almost exclusively on automotive Diesel engines. The operation of a *hydraulically* controlled closed nozzle is explained by figure 32. In the illustra-

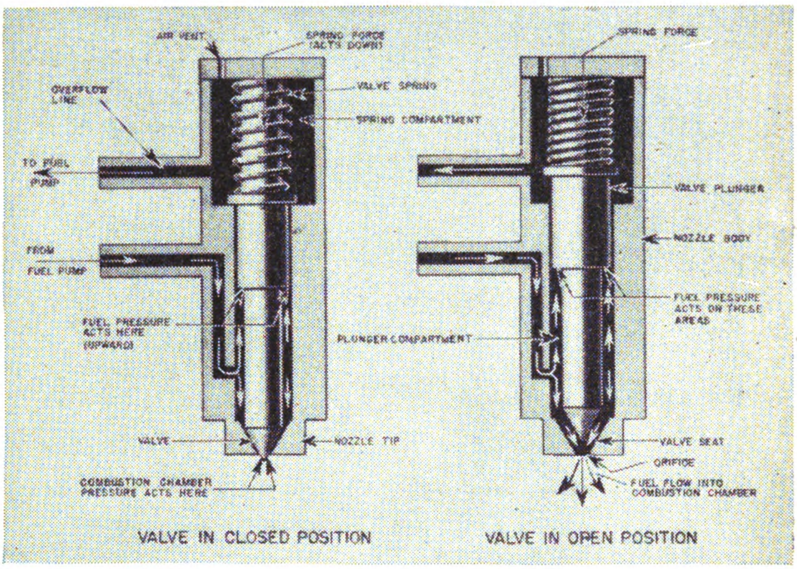



FIGURE 32.—Hydraulically controlled closed nozzle.

tion on the left, fuel is being pumped under high pressure to the fuel inlet of the nozzle and flows into the plunger compartment. Here the fuel exerts a pressure in all directions as shown by the small arrows. At the same time, the pressure of the compressed air in the combustion chamber exerts an upward force on the lower portion of the valve. The valve is lifted off its seat when the combined pressures of the fuel and compressed air are sufficient to overcome the downward force of the valve spring. The illustration on the right shows the fuel flowing around and underneath the valve, lifting it still higher without any increase in fuel pressure. When the required quantity of fuel has been supplied for each injection, the pressure acting upward on the valve plunger decreases to less than that of the downward spring force and consequently the valve closes again.

*b.* The lower portion of valve plungers is usually conical or stepped in shape to provide different pressure areas for different amounts of

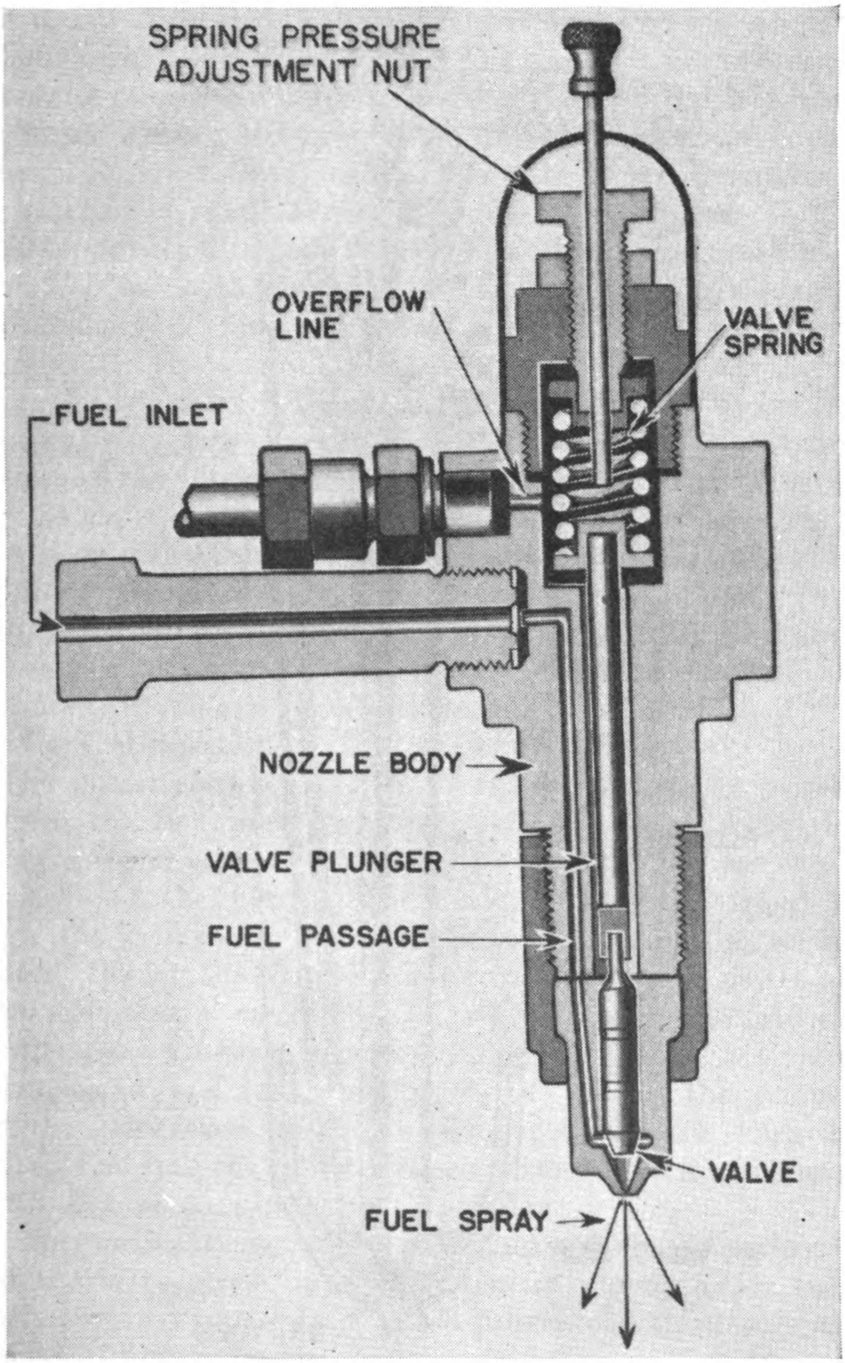



FIGURE 33.—Hydraulically controlled open nozzle.

valve lift. This variation in area is known as a differential area and is utilized to control the rate of fuel injection. It is important that

the valve opens widely and suddenly so that the fuel assumes its normal flow as rapidly as possible. Similarly, the valve should close

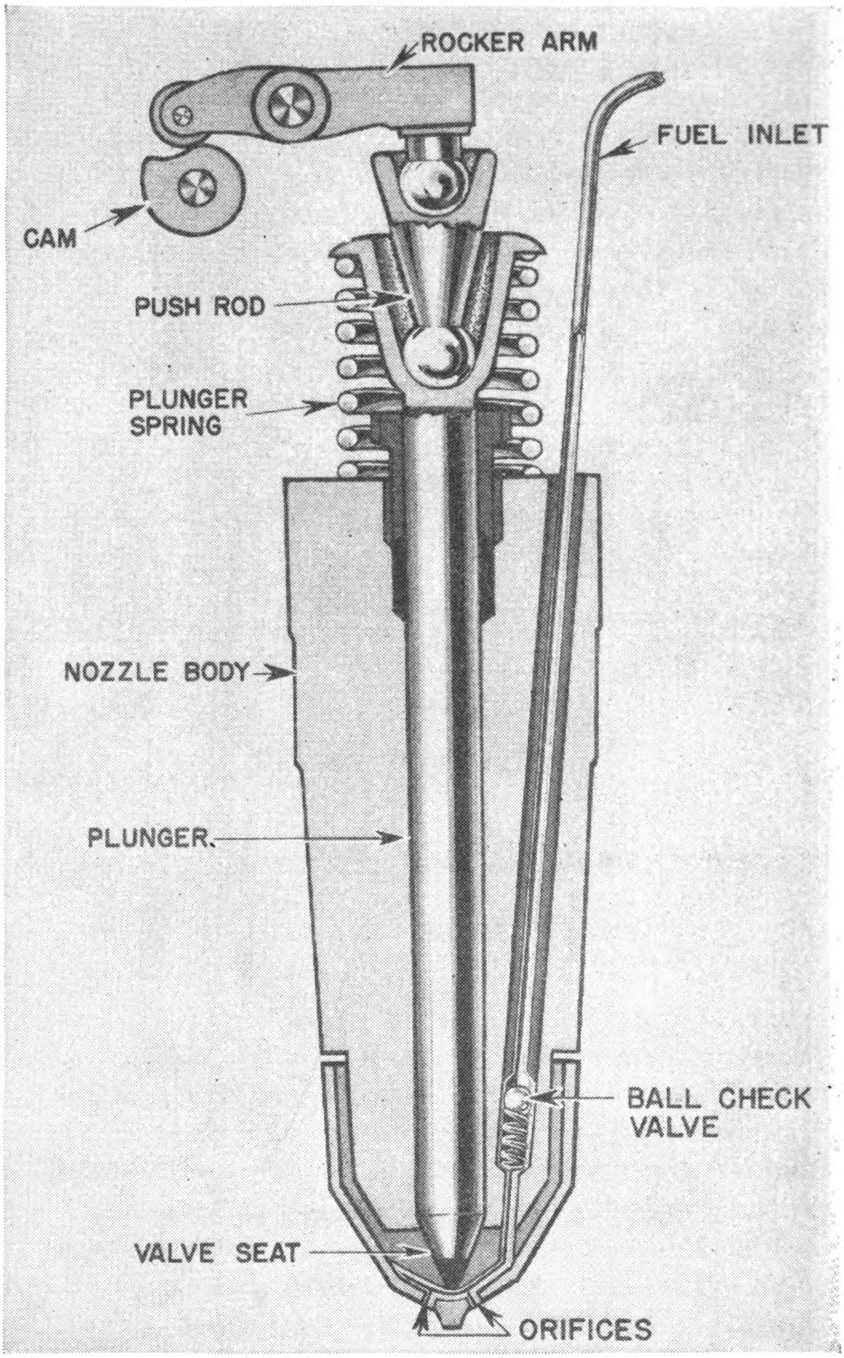



FIGURE 34.—Mechanically operated closed nozzle.

promptly to sharply cut off the fuel injected and thus prevent "dribbling."

*c.* An overflow or drip return line is incorporated in the upper part of the nozzle (figs. 32 and 33) to carry any fuel leaking past the plunger into the spring compartment back to the fuel pump. An air vent is usually provided in the upper part of the spring compartment to dispose of any accumulated air. The spring is always set to open at a definite pressure, usually from 1,500 to 4,000 pounds. The pressure desired is obtained by regulating the spring pressure adjustment nut shown in figure 33. This nozzle is used on many popular makes of Diesel automotive truck engines.

**28. Mechanically operated closed nozzle.**—*a.* These nozzles are suitable for use with air injection engines, or with engines using the "common rail" method of fuel injection which is discussed in paragraph 31. It is similar to the hydraulic nozzle in that it has a spring loaded valve. The valve, however, instead of being lifted hydraulically by fuel pressure is actuated by a cam and rocker arm the same as the intake and exhaust valves of the gasoline engine. Figure 34 shows a typical mechanically operated closed type nozzle employed on many truck engines. The spring acting upward always keeps the valve plunger in contact with the push rod. Thus any motion imparted to the push rod by the cam will be transferred to the valve plunger and valve. Since the cam can be made to have any desired lift, it affords a positive and accurate method of regulating the fuel injection.

*b.* The nozzle shown in figure 34 receives a definite quantity of fuel from the fuel inlet with sufficient pressure to force the ball check valve open and allow the fuel to enter the hot recesses in the lower part of the nozzle. The fuel is prevented from flowing through the orifices by the high pressure within the combustion chamber. During the compression stroke the plunger moves upward and *hot compressed air enters the nozzle* through the orifice, occupying the space formerly taken by the plunger. This hot air vaporizes the heated fuel oil. Just before the end of the compression stroke the cam forces the valve plunger downward, spraying the vaporized fuel into the combustion chamber where it is immediately ignited. Figure 35 illustrates this action.

**29. Magnetically actuated injection nozzle.**—Another nozzle, one of the more recent injector system developments, is the magnetically actuated type. It has been proven experimentally and has been successfully applied in special cases. The chief features of this nozzle are the sharp cut-off and accurate metering of the fuel. These are made possible by the quick response of the nozzle plunger which is controlled electrically.

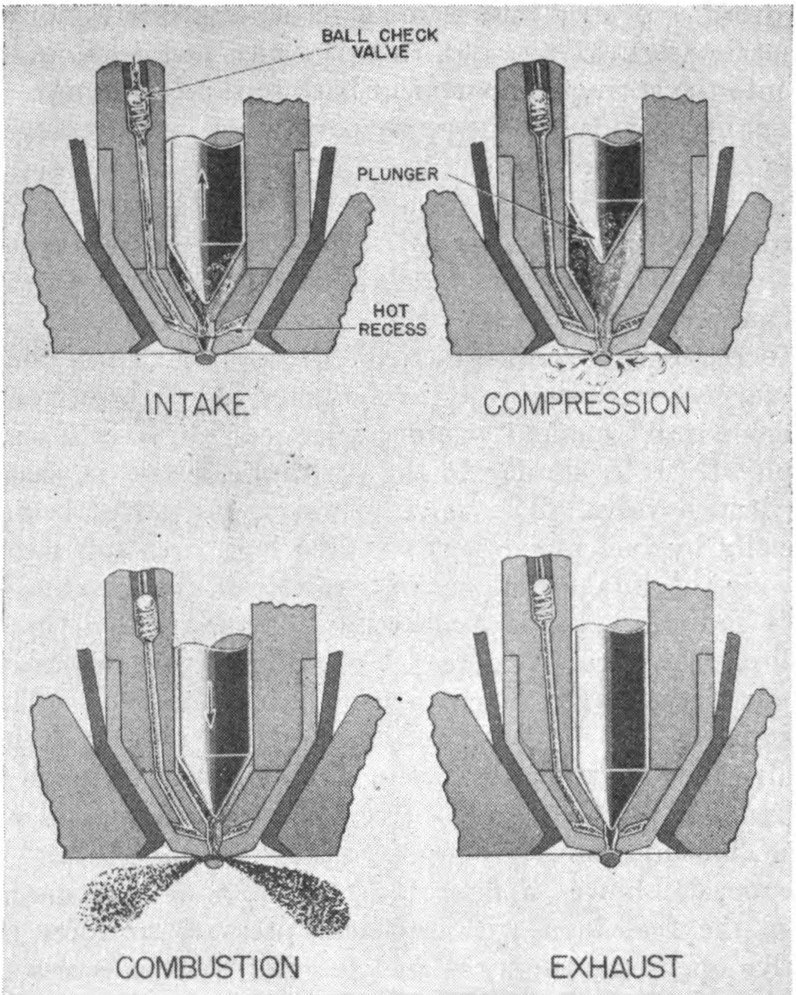



FIGURE 35.—Operating sequence of mechanically controlled closed nozzle.

## SECTION VI

## FUEL INJECTION PUMP



**30. General.**—*a.* Fuel injection pumps deliver the correct amount of fuel at the proper time to the injection nozzle to produce the most satisfactory engine performance. If the injection timing is

incorrect the cylinder pressure wil rise unevenly, the piston power impulses will be irregular, and consequently the engine power will be rough. An error in timing as small as ½° of crankshaft rotation will make a noticeable difference in the operation of a Diesel engine; a variation of 2° will seriously impair its efficiency. The speed of an engine influences the timing of the fuel injection to a great extent because the higher the engine speed the less time there is for complete combustion. A given quantity of fuel will vaporize, ignite, and burn in a definite time. Therefore, fuel injection must begin earlier and end later when engine speeds are increased.

*b*. Considering the quantities of fuel that must be injected for each working stroke of a Diesel engine will illustrate the accuracy with which a fuel pump must work. A typical four-cylinder Diesel having a bore of 4¾ inches and a stroke of 6½ inches operating at full load at 1,250 r. p. m. requires 0.0025 pounds of fuel for each cylinder per stroke. The maximum duration of injection is about 30° of crankshaft rotation; therefore, this small quantity of fuel must be accurately measured and injected within $\frac{2}{1000}$ of a second.

*c*. Since the load on an automotive engine fluctuates considerably, the amount of fuel needed to develop the necessary power varies accordingly. Thus it is important that correct quantities of fuel are delivered to the cylinders to meet each variation in operating conditions. There are two fundamental systems of fuel injection, the common rail and the injection pump, sometimes called the "jerk" system. The latter system is used almost exclusively on automotive Diesel engines.

**31. Common rail system.**—*a*. In this system one pump continually supplies a common rail, or reservoir, with fuel at high pressure. Fuel flows from this common rail to each cylinder through the injection nozzles, which are opened mechanically by a correctly timed cam arrangement driven from the engine crankshaft. When an injection nozzle opens, fuel flows under pressure from the common rail into the combustion chamber.

*b*. In the common rail system the proper injection pressure is available at the injection nozzle throughout the entire injection period. However, nozzles subjected to high pressure at all times must be accurately constructed and adjusted in order to control exactly the lift of the injection nozzle valve and to divide the load equally between the cylinders. Mechanically operated common rail systems are not well adapted to speeds above 800 to 1,000 r. p. m. and are therefore used mainly on marine and stationary engines.

**32. Distributor system.**—*a.* A modification of the common rail system, employing a single pump and a distributor, has been developed and used successfully for many years. Each nozzle is connected to the common fuel supply through a single distributor unit as illustrated in figure 36.

*b.* In the distributor system, a single, variable stroke pump meters the proper quantity of fuel and continually delivers it at a low pressure (50 to 100 pounds per square inch) to the distributor. The distributor, as its name implies, distributes the fuel charge to the various injection nozzles. These nozzles are cam-operated and control the time and duration of the fuel injected into the combustion chamber.

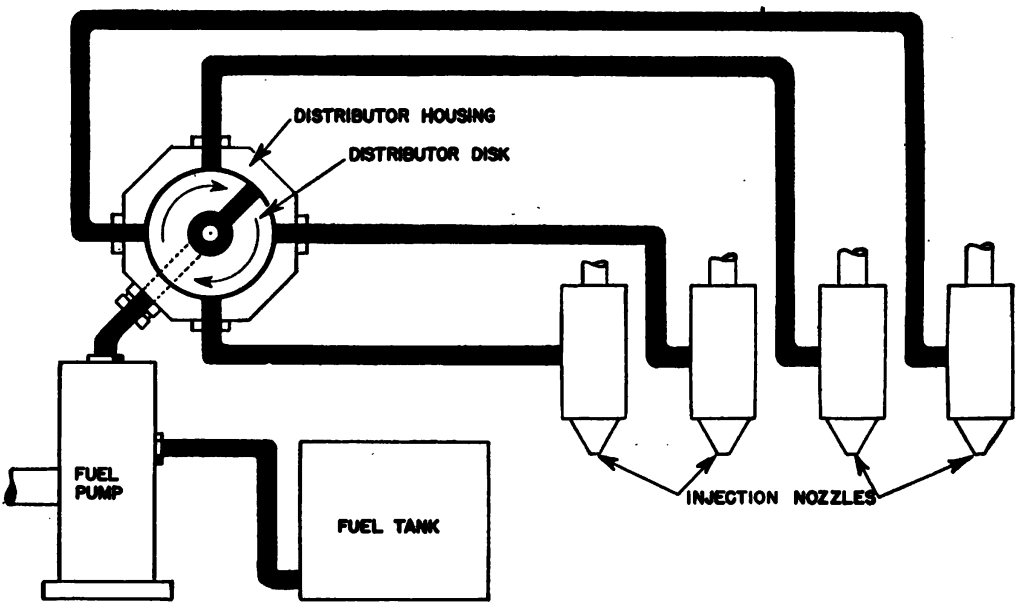



FIGURE 36.—Distributor system of fuel injection.

The nozzle plungers raise the fuel pressure to approximately 15,000 pounds per square inch, as required for injection.

*c.* The rotary distributor, a disk having a hole or port in it, is held firmly against the distributor case by the tension of a spring, as shown in figure 37. In the bottom of the case are holes which lead directly to the injection nozzles in the respective engine cylinders. As the disk rotates, the hole in it comes in line successively with each hole in the distributor case, thereby delivering fuel to each nozzle at the proper time.

*d.* The advantages of this system of fuel supply are—

(1) Elimination of fuel pressure on the nozzles except at the time of injection.

(2) Positive and equal distribution of fuel to all cylinders.

(3) Low pressures until the very last stage of fuel injection is reached.

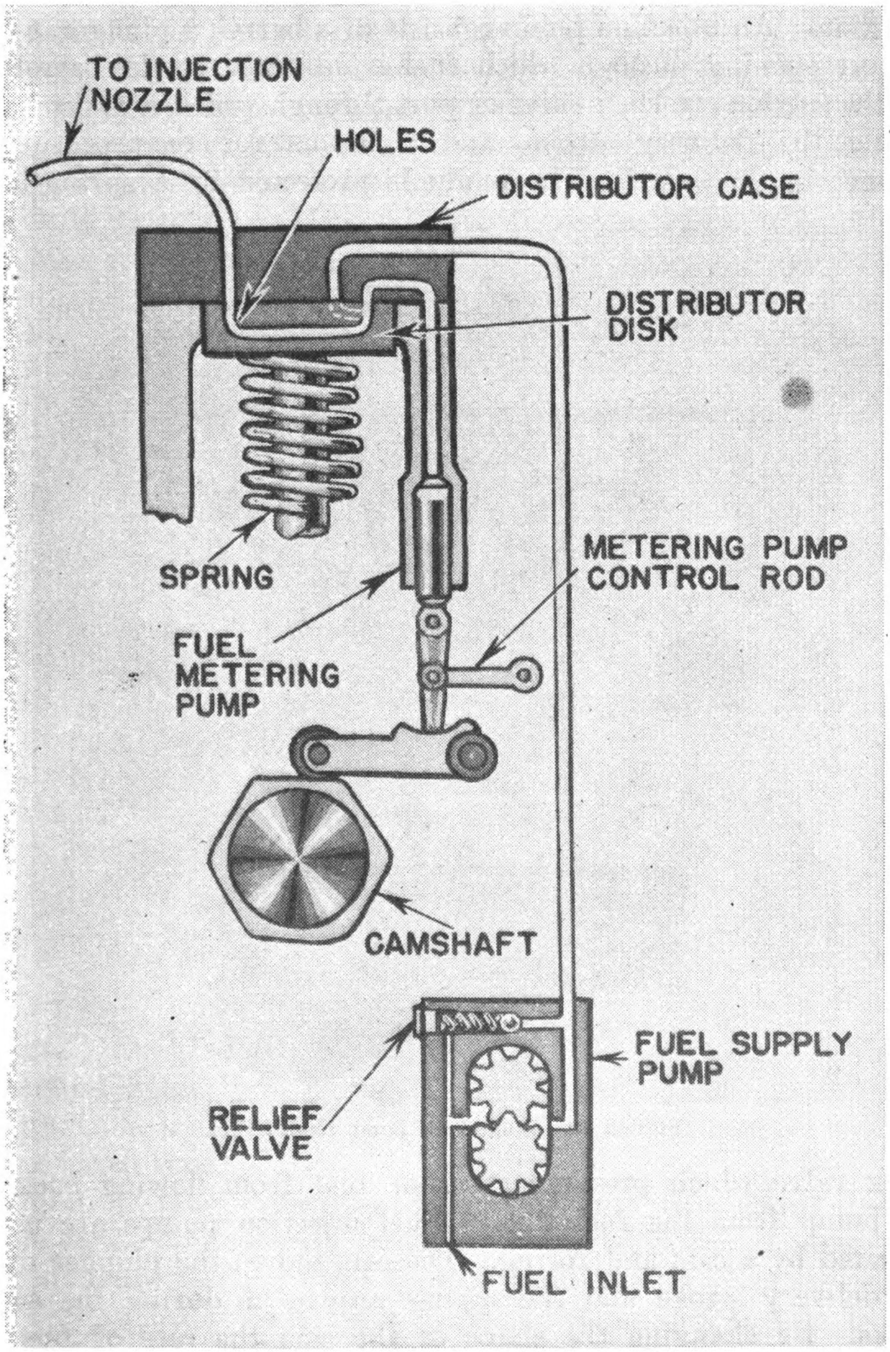



FIGURE 37.—Operation of fuel distributor system.

Low fuel pressure is desirable because it minimizes fuel leakage, dribbling, and wear on moving parts.

**33. Injection pump system.**—*a.* The injection pump system is the most widely used fuel injection system on automotive Diesels. The pump itself controls the exact quantity of fuel and the time of injection. An injection pump consists of a barrel, a plunger, a valve or port opening through which fuel is admitted to the barrel during the suction stroke, a valve or port through which it is discharged during the delivery stroke, and a means for reciprocating the plunger in the barrel. The pump is protected by a spring-loaded

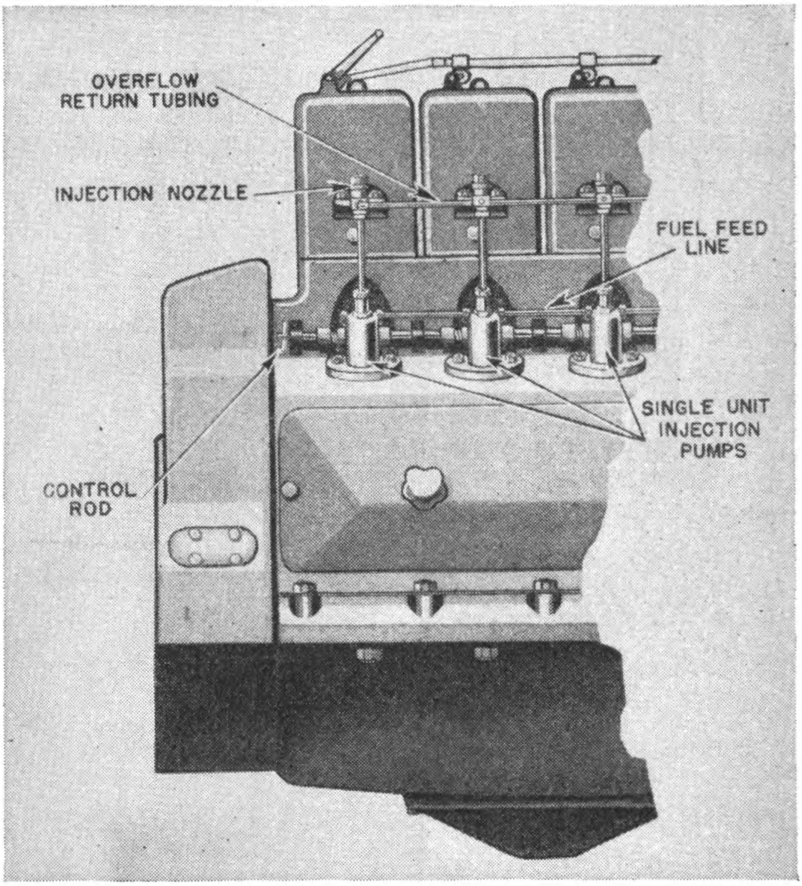



FIGURE 38.—Single-unit pump installation.

check valve which prevents gases or fuel from flowing back into the pump from the fuel line. Fuel injection pumps are usually operated by a cam and spring. The cam moves the plunger during the delivery stroke and the spring returns it during the suction stroke. By changing the shape of the cam the rate of fuel feed can be adjusted. These cams are coupled with the engine crankshaft by means of gears or a chain.

*b.* Owing to the high pressures against which the pump must work and the great accuracy required in metering and timing the injec-

tion, the elements must be made of high grade material if the pump is to give long service. Pump parts must be rigid and accurately machined since the oil leakage is controlled by the accuracy with which the moving parts are fitted together.

*c.* In this system each cylinder has its own injection pump. The necessary pumps for a multiple cylinder engine may be mounted either as individual units or as a group in one common housing. The advantage of units individually mounted is apparent; if one pump fails it can be replaced without disturbing the others. When the pumps are grouped in one housing they are arranged so that the fuel lines connecting the fuel pump with the injection nozzles do not cross. Such a construction makes the installation neat, compact,

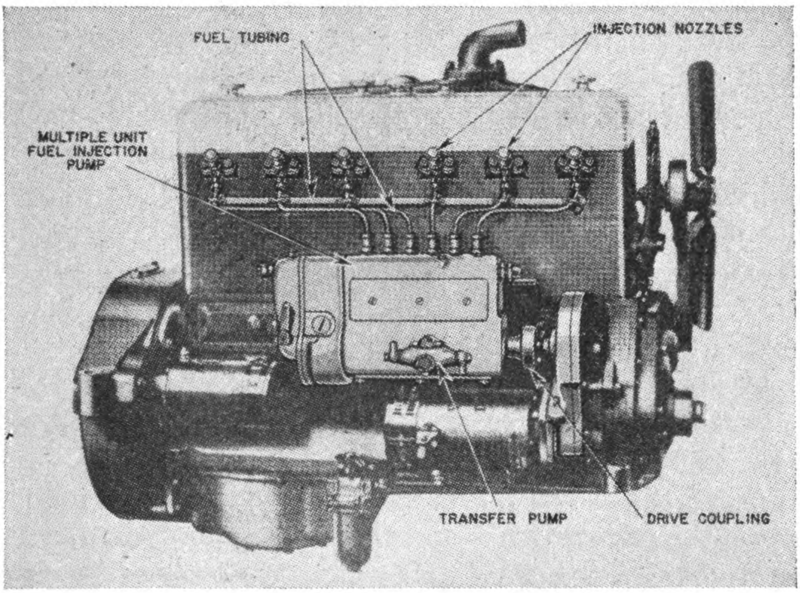
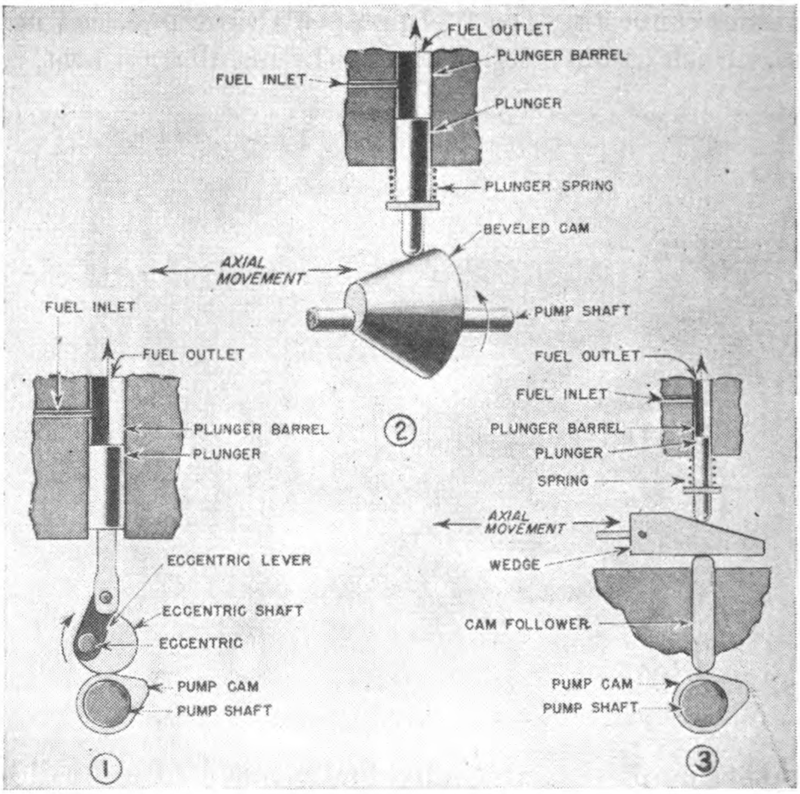



FIGURE 39.—Multiple-unit pump installation.

and rigid. Pumps that are individually mounted are called single unit pumps, while those grouped in a single housing are referred to as multiple unit pumps. Figures 38 and 39 illustrate typical pumps of each type.

*d.* Injection pumps may be subdivided into two main groups, variable stroke and constant stroke. The variable stroke pumps are more commonly used. In this type of pump the travel of the pump plunger is varied to suit the changes in volume of fuel to be injected. The pump valves are not used for regulating the quantity of fuel delivered. In constant stroke pumps the length of plunger stroke is fixed and the quantity of fuel is varied by controlling the valve action of the pump.

**34. Variable stroke pump.**—*a.* The longer the stroke or travel of the pump plunger the greater its displacement. The length of a stroke can be varied in a number of different ways. The simplest method makes use of an inclined or beveled cam which can be moved axially. Another method of varying the effective stroke consists of transmitting the cam motion through an eccentric which controls the position of the plunger in the pump barrel. Inserting a wedge between the cam and the pump plunger is still another way of varying the effective stroke.




① Eccentric lever. ② Inclined beveled cam. ③ Wedge.

FIGURE 40.—Types of variable stroke fuel injection pumps.

*b.* Figure 40② illustrates the inclined or beveled cam principle. It is evident that if the cam is moved axially to the right, the plunger lift (stroke) will be decreased. The plunger automatically tends to seek the smaller end of the cam, while a considerable force is required to move the cam in the opposite direction so that the plunger will ride the larger end of the cam. For this reason inclined cams are seldom used.

*c.* Figure 40① shows a typical method of varying the effective stroke of the pump by an eccentric. The volume of fuel drawn into

the pump barrel is proportional to the distance the plunger travels below the fuel inlet. When the eccentric is in its bottom position this distance is greatest, thereby admitting a maximum volume of fuel into the barrel. Rotating the eccentric so that it is in its highest position shortens the distance and decreases to a minimum the volume of fuel admitted. Intermediate positions of the eccentric make possible a variable fuel delivery between these limits.

*d.* A simple wedge method of varying the fuel quantity is illustrated in figure 40③. It may be seen that movement of the wedge from left to right decreases the effective stroke of the plunger in the same manner as rotating the eccentric in figure 40①.

**35. Constant stroke pump.**—*a.* The greater percentage of automotive Diesel engines employs the constant stroke fuel injection pump. In these pumps the plunger stroke remains constant at all loads, and fuel injection begins at the same time for every load. The fuel cut-off (end of injection) is timed to occur earlier or later as demanded by the load on the engine. This timing is accomplished by regulating the time the overflow or bypass valves open and close. There are several methods of controlling the bypass as well as various valve arrangements. Figure 41 illustrates several constant stroke pumps.

*b.* Figure 41① shows the bypass through an auxiliary valve (throttle valve) controlled by a rocker arm and eccentric. One end of the rocker arm travels up and down with the pump plunger, while the pivot point at the other end may be raised or lowered by rotating the eccentric. As the rocker arm is raised the throttle valve stem is lifted, reducing the clearance between the valve stem and the throttle valve. Consequently, the throttle valve will open sooner and remain open longer so that more fuel will be returned from the pump chamber to the fuel supply as a direct result of this decreased clearance. The volume of fuel delivered for injection is thus controlled for any desired operating conditions of the engine. This method, known as throttle regulation, is extremely simple in construction and is mainly used on small precombustion chamber engines which require low fuel injection pressures.

*c.* Figure 41② shows a needle valve controlling the amount of fuel bypassed. The valve stem is threaded so that turning the throttle lever adjusts the opening of the needle valve. When the throttle lever moves the valve in toward the valve seat the volume of fuel bypassed decreases. Thus more fuel is retained in the pump chamber for delivery to the injection nozzle. The needle valve is threaded in such a way that some fuel is always bypassed throughout

the injection stroke of the plunger, the amount permitted to escape being governed by the position of the throttle lever.

*d.* The pump shown in figure 41③ is similar to the pump shown in figure 41① except that no auxiliary valve is used. In this case

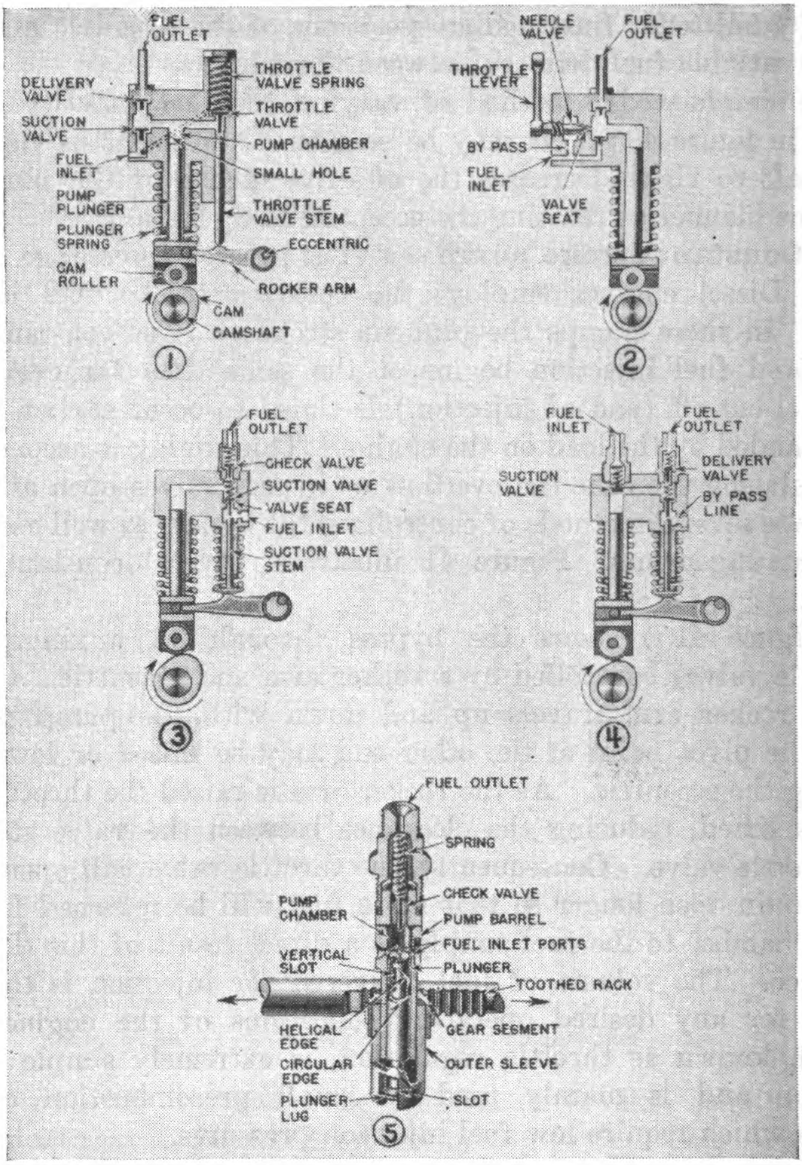



FIGURE 41.—Types of constant stroke fuel injection pumps.

the suction valve acts also as a bypass or throttling valve. The valve stem actuated by the rocker arm controls the suction valve, holding it open to permit fuel to flow from the pump chamber back into the fuel supply. The amount and length of time that the suction valve is held open is determined by the adjustment of the

eccentric. As fuel pressure cannot be built up within the pump chamber unless the suction valve is seated, the volume of fuel delivered to the injection nozzle is controlled. The longer the suction valve is held open the more fuel is bypassed and the less fuel enters the nozzle. A decided advantage of suction valve control is that the time the fuel is cut off can be accurately adjusted because the control mechanism is not influenced by the fuel injection pressure.

*e.* The pump shown in figure 41④ is merely a different arrangement of the component parts of the pump illustrated in figure 41①. It is a method commonly used as it gives a sharp fuel cut-off which is desirable.

*f.* Over 75 percent of the present automotive Diesel engines use a fuel injection pump wherein the quantity of fuel delivered to the injection nozzle is regulated by the plunger uncovering a bypass or inlet port. This type of pump avoids the necessity of fuel-

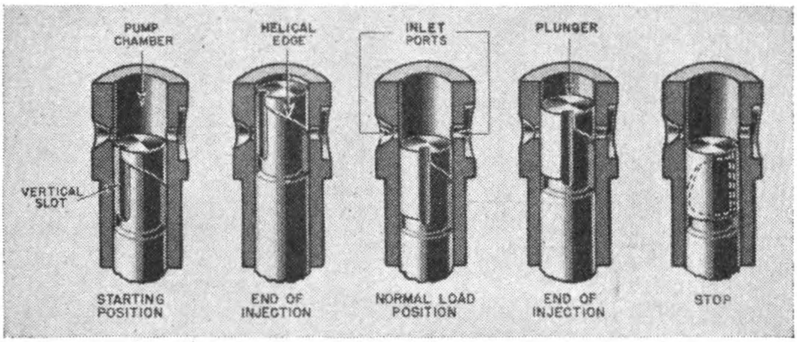



FIGURE 42.—Operation of port control fuel injection pump.

controlling valves. Control is effected by rotating the pump plunger.

*g.* In figure 41⑤ it is seen that two fuel inlet passages lead to the plunger barrel. The plunger has a groove around its circumference which has a circular lower and a helical upper edge. The space thus formed communicates with the top face of the plunger through a vertical slot. Hence, any fuel above the plunger will flow down the vertical slot and fill the helical space. At the lower end of the plunger are two lugs which fit into corresponding slots in the bottom of an outer sleeve fitted around the pump barrel. The upper part of the sleeve is fastened to a gear segment which meshes with a horizontal toothed rack. Any axial movement of the toothed rack rotates the outer sleeve and plunger, relative to the two inlet ports in the stationary pump barrel.

*h.* At the beginning of the discharge or delivery stroke (fig. 42) the pump plunger is below the inlet ports, permitting the fuel to

flow into the pump chamber, vertical slot, and helical groove. The auxiliary pump supplying the pressure to make this possible will be explained later under fuel systems. When the plunger begins its upward movement, it gradually covers the two inlet ports preventing further admission of fuel. The continued movement of the plunger increases the pressure of the trapped fuel until the spring force of the check valve is overcome, at which point fuel is sent to the injection nozzle. However, before the end of the discharge stroke the helical edge in the plunger uncovers the inlet port to the right, allowing the fuel to flow back to the inlet. This produces an im-

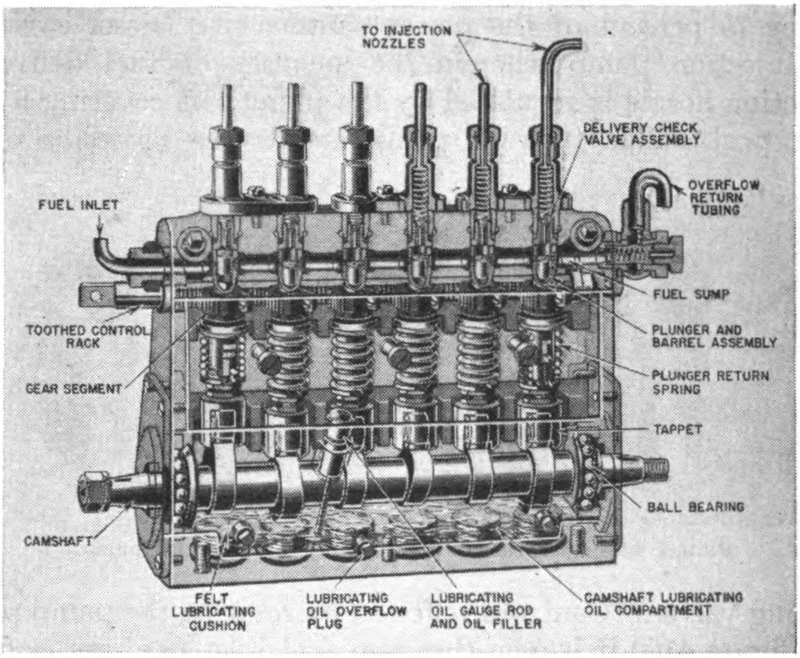



FIGURE 43.—Phantom cross section view of typical multiple unit fuel injection pump.

mediate drop in fuel pressure so that the check valve closes sharply thus stopping further fuel delivery to the injection nozzle.

*i.* Rotating the pump plunger by means of the toothed rack causes the helical groove to uncover the inlet port to the right sooner or later during the stroke of the plunger, thereby controlling the amount of fuel delivered for every throttle position. In this way the fuel charge is made to suit the engine load requirements. A phantom cross section view of a typical multiple unit fuel injection pump employing the principle just described is shown in figure 43. It should be noted that the same toothed rack controls the rotation of all the plungers equally and simultaneously.

**36. Unit injector.**—*a.* This is a further adaptation of the principle of metering fuel by having the pump plunger uncover a bypass port. It is unique in that the discharge end (bottom) of the pump contains a nozzle. Thus the unit injector combines in a single unit all the parts necessary to meter, atomize, and inject the fuel under

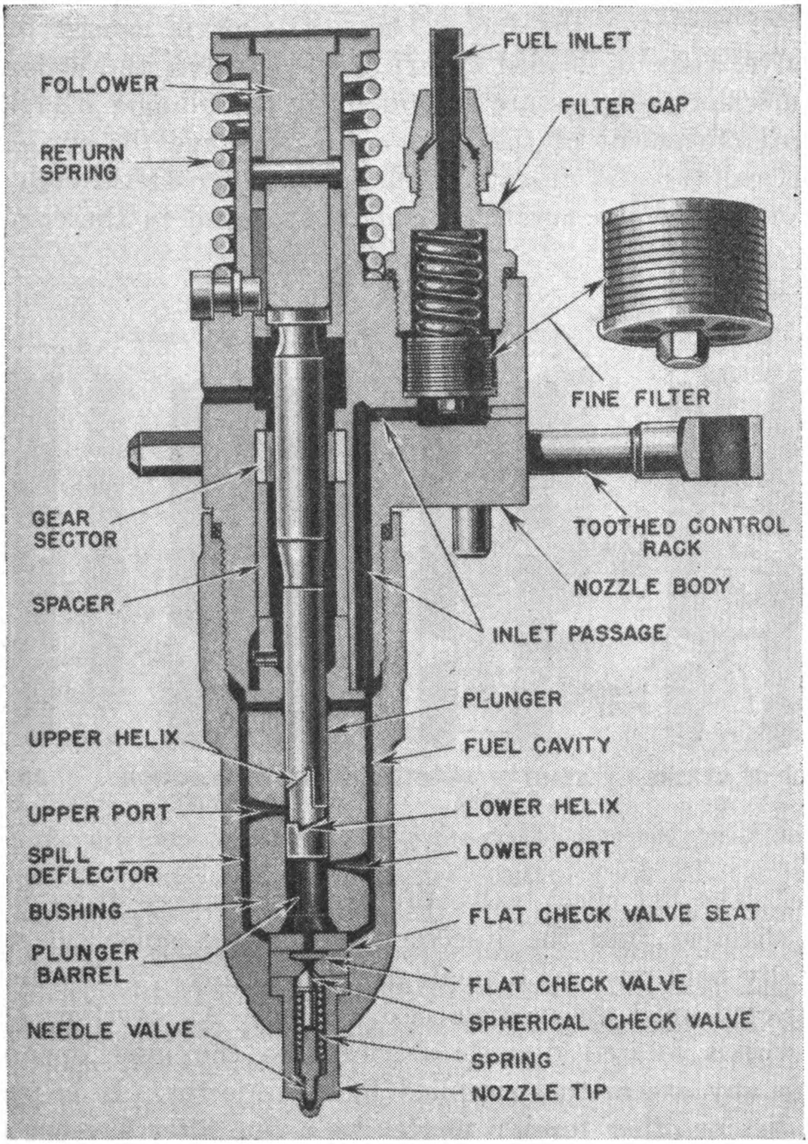



FIGURE 44.—Cross section view of unit injector.

high pressure into the combustion chamber. It provides a complete and independent injection system for each engine cylinder.

*b.* The cross section of a unit injector (fig. 44) shows the various parts that make up a complete injector. Fuel oil is supplied to the

injector at a pressure of about 20 pounds per square inch, and enters the filter cap at the top of the nozzle body. It flows through a fine filter into an inlet passage where it fills the fuel cavity in the bushing surrounding the plunger. Two funnel-shaped ports (upper and lower) connect the fuel cavity to the plunger barrel (high pressure cylinder). The plunger has two helices (upper and lower) for the purpose of metering the fuel. The nozzle parts consist of a flat check valve, a spring-loaded spherical check valve, and a nozzle tip. When sufficient fuel pressure is built up in the plunger barrel by the downward movement of the plunger to overcome the spring force, the spherical valve is unseated and the fuel forced through several minute orifices in the nozzle tip and is atomized in the combustion

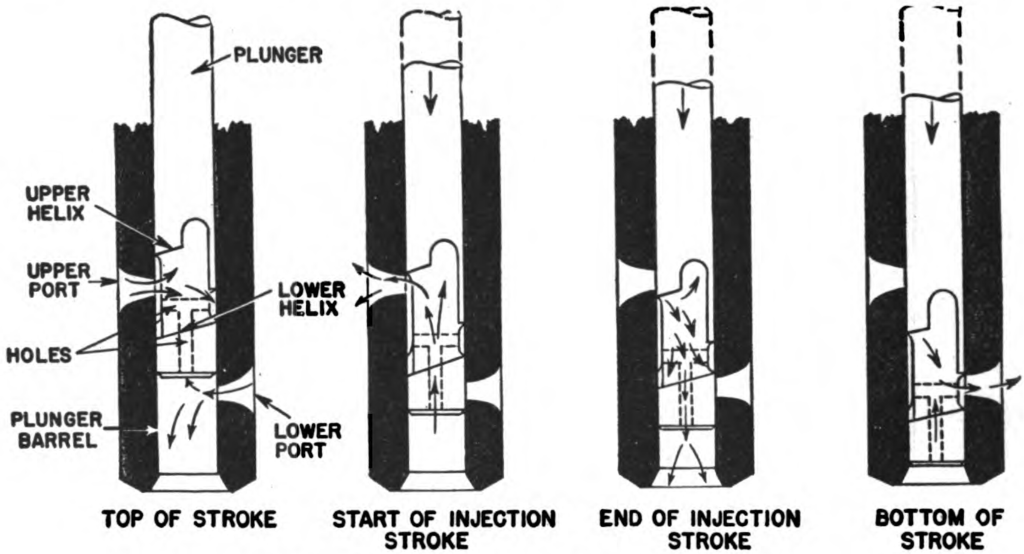



FIGURE 45.—Action of vertical travel of plunger.

chamber. The flat check valve prevents air leakage from the combustion chamber into the injector, in case the spherical valve is accidentally held open by a small particle of dirt. This allows fuel to be injected until the particle is dislodged. An overflow opening, not shown, is located directly adjacent to the inlet opening for returning any excess fuel supplied to the injector. It is protected against dirt or other foreign matter by a fine filter element exactly like the one on the inlet side.

*c.* (1) The action of the vertical travel of the plunger will be explained by referring to figure 45. As the lower edge of the plunger uncovers the lower port of the fuel cavity on the upward stroke, fuel fills the barrel and flows through the two small holes in the plunger to the recess between the two helices. On the downward

stroke, the fuel is first forced back through the upper and lower ports into the fuel cavity until the lower edge of the plunger closes the lower port. Then the fuel remaining in the barrel and recess is forced back into the cavity through the upper port only. When the upper helix closes the upper port as the plunger continues to move down, fuel is trapped in the barrel and recesses of the plunger. Fuel pressure is then built up until the pressure is sufficient to unseat the check valve in the nozzle part at which time fuel injection begins.

(2) The relation of the two helices of the plunger to the upper and lower ports of the fuel cavity changes with the rotation of the plunger. In this way the quantity of fuel bypassed and the period of fuel injection may be controlled so that the desired amount of fuel is delivered to the engine cylinders at the proper time. Figure

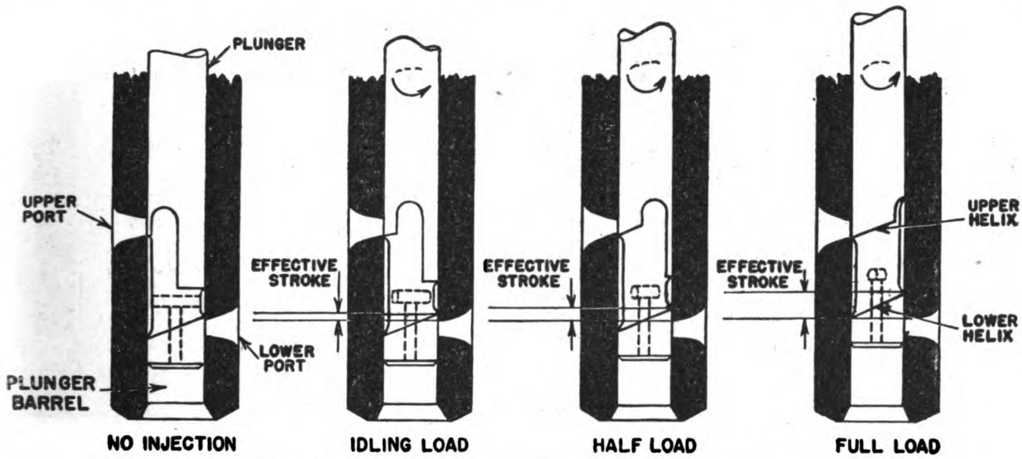



FIGURE 46.—Action of rotating the plunger.

46 shows the effects of rotating the plunger to various positions from "full load" to "no load". With the control rack of the injector pulled out completely (no injection), the upper port is not closed by the upper helix until after the lower helix has uncovered the lower port. Consequently, with the control rack in this position, all the fuel charge is forced back into the fuel cavity and no injection occurs. With the control rack pushed in completely (full load), the upper and lower ports close simultaneously, thus producing a full effective stroke and maximum injection. Between these two positions the plunger may be rotated to meet all conditions of engine operation.

*d.* Unit injectors are mounted in the cylinder head of the engine as shown in figure 47. They fit into water-cooled copper tubes and are held in place by hold-down bolts to the cylinder head. The

tapered seat at the bottom of the injector forms a tight seal between the copper tube and the nozzle to withstand the high compression pressures inside the combustion chamber. The camshaft is gear driven by the crankshaft and actuates a rocker arm which controls the downward movement of the injector plunger. The plunger may be rotated by a toothed control rack in the same manner as the pump previously discussed. The toothed control rack is connected through

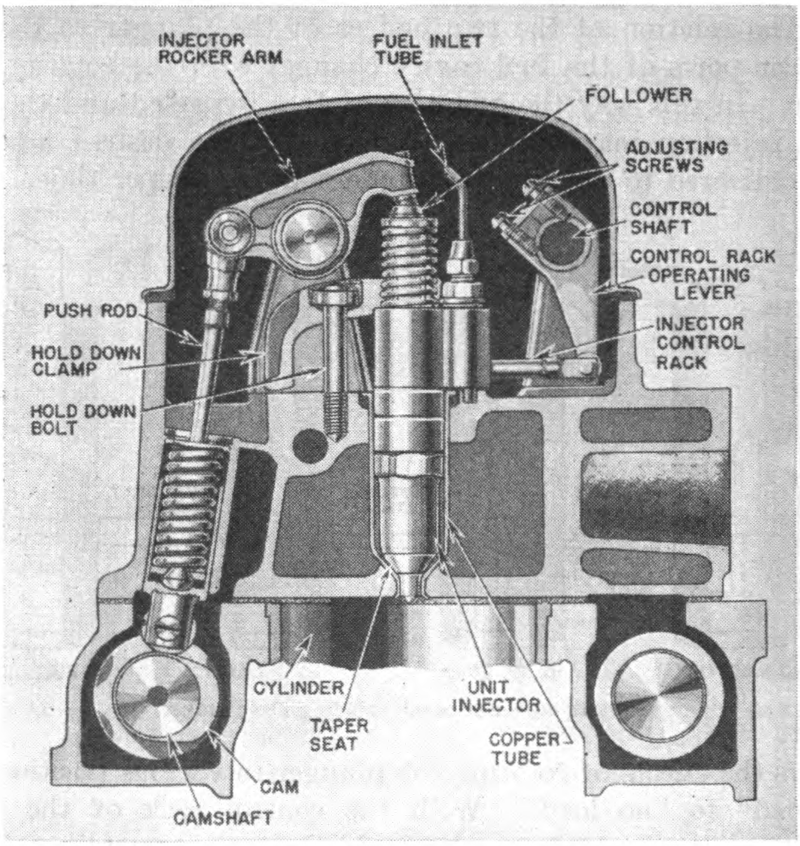



FIGURE 47.—Unit injector mounting.

a detachable joint by an operating lever to a common control shaft so that any movement of the throttle lever rotates the plungers of all cylinders an equal amount. The position of the operating levers can be changed by two adjusting screws on the control shaft to permit setting each injector uniformly.

**37. Wobble plate injection pump.**—*a.* In this type of constant stroke multiple unit injection pump, the plungers are located in a circle around a central fuel metering valve and are operated by a single cam (wobble plate). The complete pump (fig. 48) may be divided into three main units, control, drive, and pump. The control

unit is mounted on top of the drive unit and merely contains the arms or levers by which the motion of the operator's controls are transmitted to the pump. The drive and pump units will be described by reference to the cross section view in figure 49.

*b*. The drive unit is flange-mounted to the timing gear case of the engine and contains all the parts required for actuating the pump plungers and driving the metering valve. A drive gear, driven by the engine crankshaft, is mounted on and drives an outer sleeve (drive

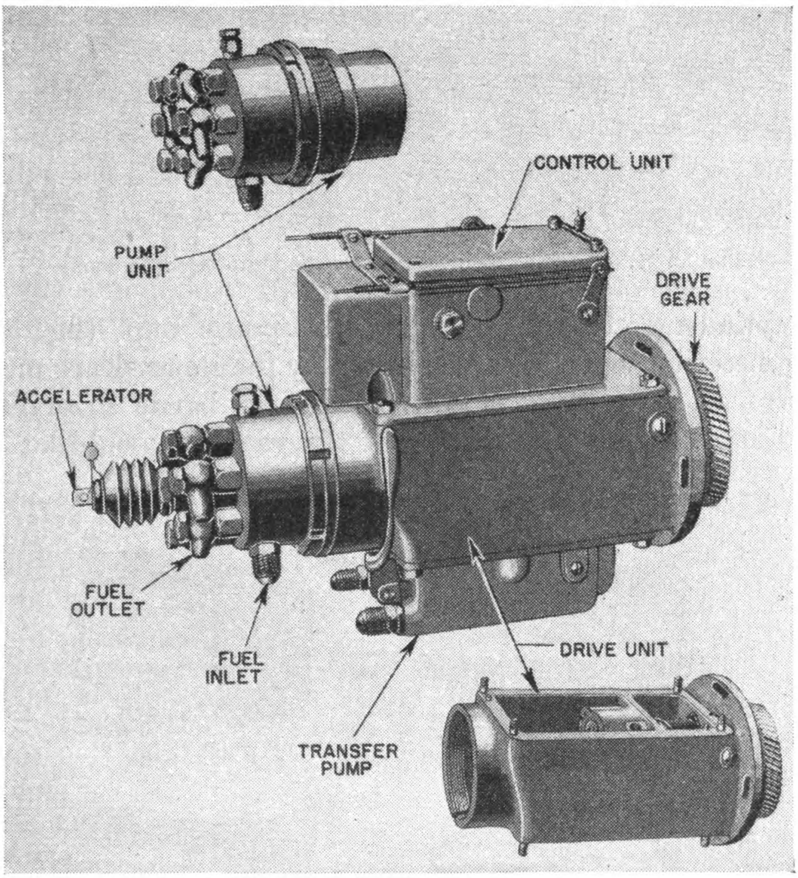



FIGURE 48.—Wobble plate injection pump.

unit shaft). This sleeve in turn drives an inner sleeve through a spiral spline at the gear end. At the opposite end, the inner sleeve is connected to the shaft of the metering valve by a straight spline. The wobble plate, which is mounted on and keyed to the outer sleeve, is simply a disk tilted at an angle to the sleeve or shaft and takes the place of the customary camshaft having an individual cam for each pump plunger. The wobble plate derives its name from the fact that it appears to wobble back and forth as it rotates. Push rods

which ride on the face of the wobble plate transmit the back and forth motion to the various plungers. All the parts in the drive unit are lubricated by the engine lubricating system.

*c*. The pump unit is mounted on the drive unit and contains the precision parts for metering and injecting the fuel into the various

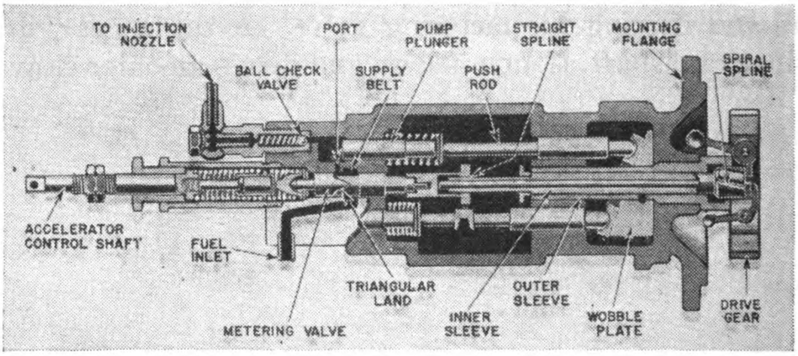



FIGURE 49.—Cross section view of wobble plate injection pump.

engine cylinders. In the center of the pump unit (fig. 50) is a rotating metering valve which is driven by the inner sleeve mentioned in *b* above. This valve is closely fitted in its barrel to prevent fuel escaping at its ends. The middle of the valve is spool-like and has

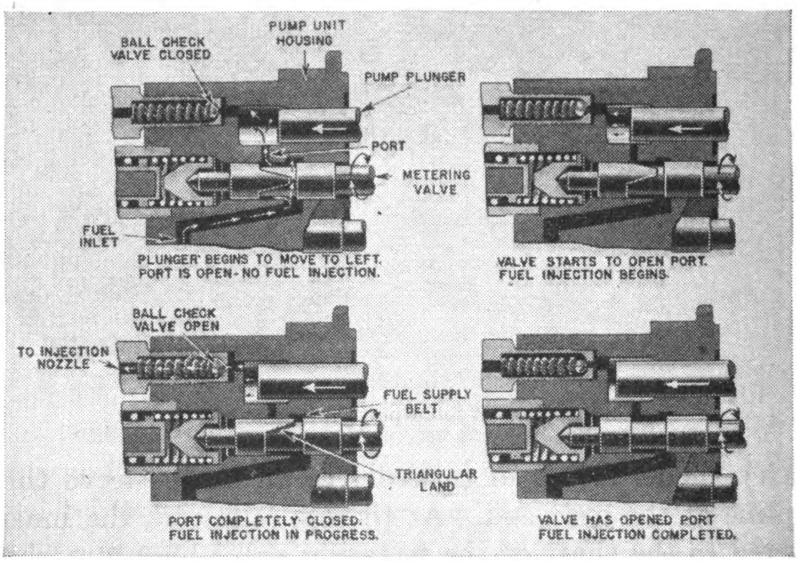



FIGURE 50.—Operation of wobble plate injection pump.

one triangular-shaped land which also makes an oiltight fit with the valve barrel. A fuel supply belt surrounds the land portion of the valve. Spaced equally around the supply belt are as many pump plungers as engine cylinders. Portholes provide a fuel passage from

the supply belt to each pump barrel. At the end of barrels are ball check valves which control the fuel delivery to the injection nozzles.

*d.* Fuel enters the inlet passage at the bottom of the pump unit into the supply belt which is filled at all times. As the valve rotates, the triangular land uncovers each port in turn so that fuel enters the barrel whose plunger is at the time in its extreme outward position. Further rotation of the valve causes the land to close the port hole, thus trapping the fuel in the plunger barrel. The rotation of the valve and wobble plate are timed with respect to each other so that when this occurs the plunger moves in, forcing the fuel out through the spring-loaded check valve from where it flows to the proper injection nozzle. These events occur in sequence for each plunger barrel as the metering valve means a complete revolution. The accelerator shaft permits the operator to shift the metering valve shaft a slight distance to the right or left. This causes the triangular land to close the ports a longer or shorter period which governs the amount of fuel entering the plunger barrel. In this way the quantity of fuel delivered to the injection nozzles may be varied to suit the operating conditions of the engine.

## SECTION VII

## FUEL SUPPLY SYSTEM



**38. General.**—*a.* The purpose of the fuel supply system is to provide clean fuel to the injection pumps at the proper pressure to insure good operation.

*b.* Every fuel supply system must have provision—

(1) Against accidental leakage and fire hazards.

(2) For filling the supply tank.

(3) For safely venting the fumes.

(4) For the expansion of the fuel in the supply tank due to temperature changes.

(5) For draining or cleaning the supply tank.

Figure 51 shows several arrangements of the parts necessary to perform these functions.

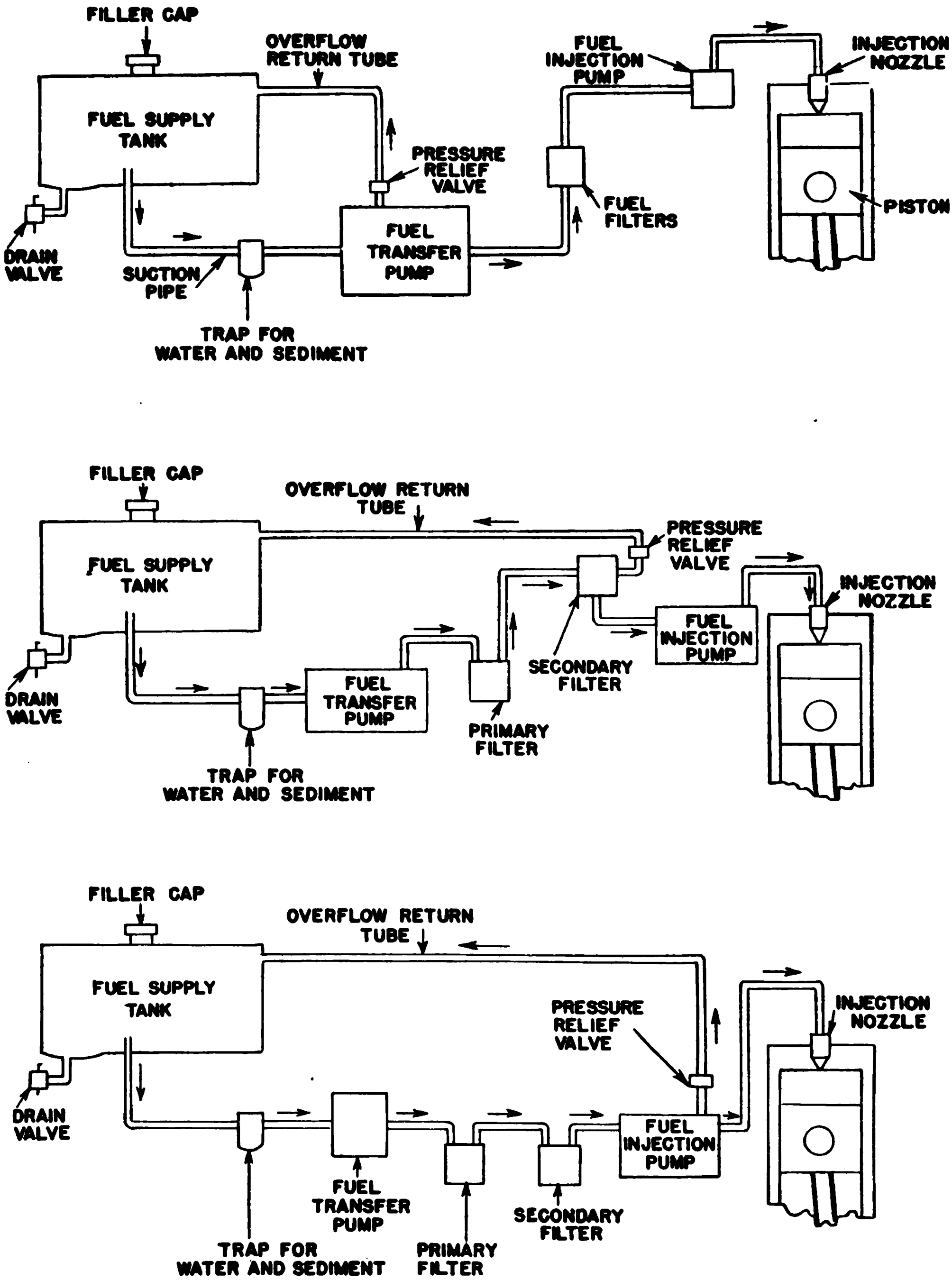



FIGURE 51.—Fuel system diagrams.

*c.* The main difference in arrangement is the location of the pressure relief or check valve. This is a simple spring-loaded overflow valve designed to hold the fuel supply in the injection pump manifold at a constant pressure. It also permits any excess fuel supplied to the injection pump by the transfer pump to return to the fuel supply tank.

*d.* It will be noted in every case that the suction pipe safely clears the bottom of the tank to avoid picking up water or sediment. The transfer pump draws the fuel from the supply tank through the filtering system and forces it into the fuel inlet manifold of the injection pump under a constant low pressure. The fuel filters are on the pressure side of the transfer pump.

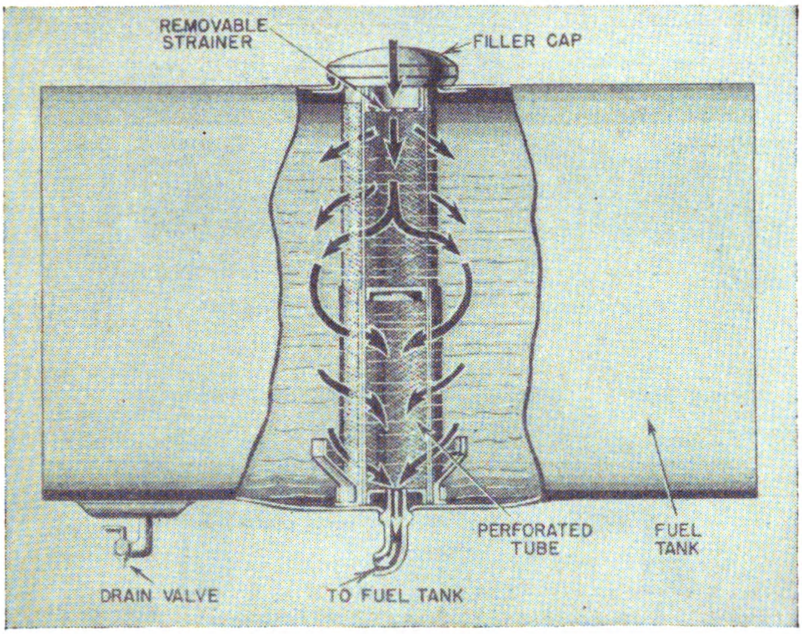



FIGURE 52.—Removable fuel tank strainer.

**39. Fuel supply tank.**—*a.* The location of the fuel supply tank is not of great importance in Diesels since a fuel transfer pump is usually employed to furnish a constant supply of fuel to the injection pump at a pressure somewhat higher than could be maintained by gravity alone. This uniform pressure fills the injection pump pumping chamber and provides regular delivery and proper metering of the high pressure fuel charge.

*b.* The general construction of the fuel supply tanks for automotive Diesel engines is practically the same as that for gasoline engines discussed in TM 10–550. Baffle plates are used inside the supply tank to prevent splashing and foaming, and the formation of

air pockets in the fuel line. In good practice the inlet or filler pipe contains a removable strainer, as shown in figure 52, which acts as a preliminary fuel cleaner or filter. A drain valve is placed in the bottom so that the tank can be drained and cleaned.

**40. Fuel transfer pump.**—The fuel transfer pump transfers fuel oil from the supply tank to the injection pump. It is located near or in most cases mounted directly on the fuel injection pump. The latter method is preferred as it lessens the length of the fuel line under pressure between the two pumps and makes a rigid compact assembly.

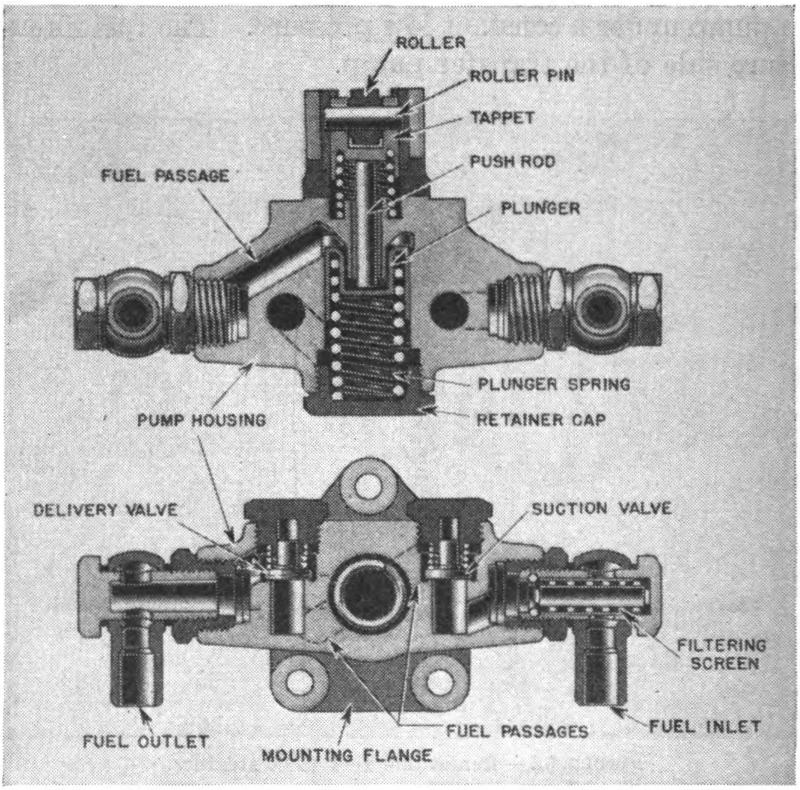



FIGURE 53.—Single acting plunger transfer pump.

Positive displacement pumps of the plunger or rotary type are always used because they have a positive suction lift and their performance is largely independent of any reasonable variations in viscosity, pressure, or temperature of the fuel.

**41. Plunger transfer pump.**—*a.* Figure 53 is a cross section of a typical single acting plunger pump. It consists mainly of a housing provided with inlet and outlet connections, plungers, plunger spring, suction valve, delivery valve, push rod, and tappet with roller. The roller and plunger are actuated by a cam from the camshaft of the injection pump. To prevent leakage of fuel along the push rod

into the camshaft compartment of the injection pump, a leak-off groove has been provided around the push rod. A passage returns the leakage fuel to the inlet connection.

(1) The operation is briefly as follows: When the roller rests on the base circle of the cam (fig. 54①) the plunger is forced downward by the plunger spring and the suction valve is opened, permitting the fuel to enter the pump plunger spring chamber. The suction also closes the delivery valve. At the same time the plunger forces fuel already in the pressure chamber through the connecting duct and fuel outlet into the supply line which leads to the injection pump. As the cam rotates (fig. 54②) the plunger is forced upward by the push rod against the plunger spring, opening the delivery

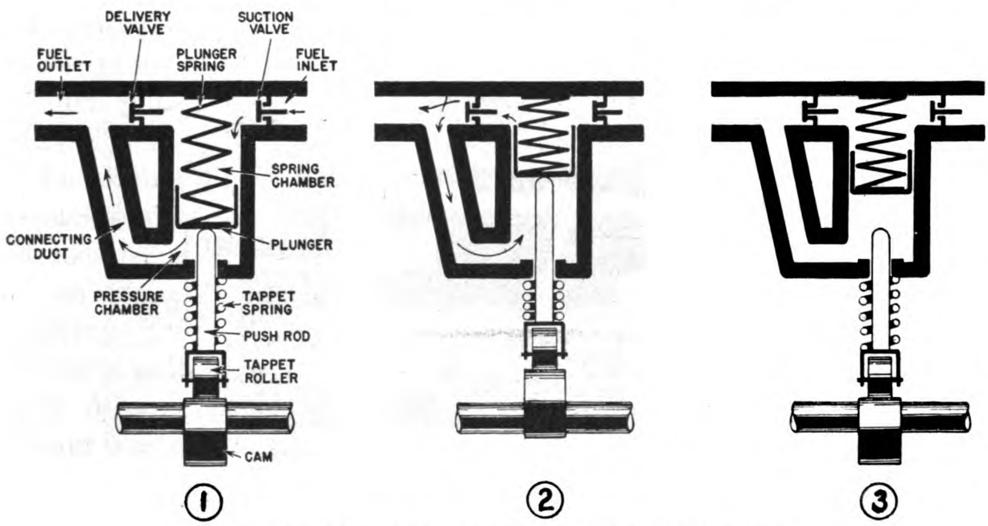



FIGURE 54.—Operation of single acting transfer pump.

valve and forcing the fuel out into the connecting duct and pressure chamber. On the next downward movement of the plunger, fuel will be delivered to the fuel outlet if the injection pump needs a further supply of fuel. If the injection pump is provided with a sufficient supply of fuel for the moment, the plunger will move downward only enough to balance the pressure between the fuel outlet and the plunger spring (fig. 54③). The push rod will leave the plunger during the rotation of the cam and will reengage only during its next upward movement. The subsequent stroke will therefore depend upon the pressure in the fuel outlet, which in turn depends on the quantity of fuel the injection pump is discharging (the fuel requirement of the engine). The greater the pressure in the delivery line, the smaller the lift of the plunger because the plunger spring can expand very little.

(2) If there were a constant fuel requirement it would only be necessary to deliver the fuel to the injection pump by the action of the upward moving plunger through the delivery valve and into the fuel outlet. If the injection pump, however, should discharge only a portion of the fuel delivered by the transfer pump into the combustion chamber of the engine, an excessively high pressure would ultimately be built up in the fuel outlet. Such a condition is prevented by the connecting duct.

(3) Single acting plunger transfer pumps are capable of working against a pressure of approximately 20 pounds per square inch. The maximum operating speeds for continuous service are 1,500 r. p. m. for small pumps and 1,200 r. p. m. for the large pumps. For intermittent service, the maximum speeds are 2,000 r. p. m. for the small and 1,800 r. p. m. for the larger transfer pumps.

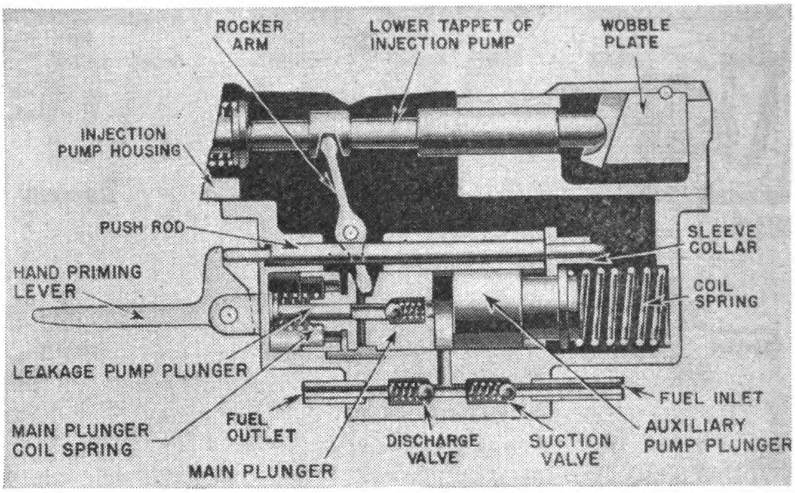



FIGURE 55.—Transfer pump used with wobble plate injection pump.

*b*. Although the fuel transfer pump used on the wobble plate injection pump is of the plunger type, it differs in operation from the pump just described. It is mounted at the bottom of the fuel injection pump as shown in figure 55. The main plunger is connected to the lower tappet of the fuel injection pump by a rocker arm so that the reciprocating motion of the tappet is transmitted to the transfer pump main plunger. The main plunger spring keeps the plunger in contact with the lower end of the rocker arm. When the plunger is moved outward by the rocker arm, fuel is drawn through the suction valve into the pump barrel. On the return movement of the plunger the fuel pressure closes the suction valve and opens the discharge valve, allowing the fuel to flow to the inlet side of the fuel injection pump.

(1) Since the main plunger has a constant stroke it is necessary to provide some means for the transfer pump to deliver a variable supply of fuel to the injection pump according to the engine needs. This is accomplished by an auxiliary spring-loaded plunger which operates at the opposite end of the same barrel as the main plunger. When the injection pump has a sufficient supply of fuel, any further delivery of fuel to it will increase the fuel pressure in the transfer pump. This increased pressure overcomes the spring force of the auxiliary plunger so that it is pushed away from the main plunger, as shown in figure 55. Thus more fuel space is created in the barrel of the transfer pump which reduces the pressure and supply of fuel to the injection pump. As the injection pump requires a greater quantity of fuel, the discharge pressure of the transfer pump drops and consequently the spring-loaded auxiliary plunger moves closer to the main plunger. This leaves less space for the fuel in the transfer pump and more fuel is delivered to the injection pump.

(2) The auxiliary plunger can be manually operated independently of the main plunger by a hand lever to prime the system with fuel preparatory to starting the engine. The hand lever actuates a push rod located above the barrel of the plungers. A sleeve collar (fig. 55) on the end of the push rod bears against a shoulder of the auxiliary plunger to force the auxiliary plunger back against the auxiliary plunger spring.

(3) A small automatic leakage pump is contained in the main plunger for picking up fuel leaking from the drive and pump units of the wobble plate injection pump. It consists of a stationary plunger which fits into a small lengthwise barrel in the center of the main plunger. As the main plunger moves back and forth it creates the same pumping effect as if the leakage pump plunger were moved and the barrel held stationary. Any fuel leaking from the injection pump drains into the automatic pump barrel through the vertical hole shown in the main pump plunger (fig. 55). When the leakage pump compression stroke begins, the leakage fuel is trapped and the increased pressure unseats a spring-loaded ball check valve in the center of the main plunger. This trapped leakage fuel escapes into the space between the main and auxiliary plungers where it is recirculated.

**42. Rotary transfer pump.**—*a.* The gear pump is perhaps the simplest type of rotary fuel transfer pump. It is mounted on the distributor unit housing. A diagrammatic sketch of this pump is shown in figure 56. In the pump body are two meshing gears, one of which is driven by the engine crankshaft. The gear teeth carry the

fuel around the case from the inlet side of the pump to the outlet side where it is forced out into the outlet tubing and delivered to the injector pump at a pressure of 50 to 60 pounds per square inch. This pressure is determined by the setting of the adjustment screw which fixes the spring force acting on the ball of the relief valve. If the pump pressure exceeds the spring pressure, the relief ball is forced back from its seat, allowing fuel to bypass back to the intake side of the gears. This method insures a complete filling of the metering pump plunger chamber at any speed within the limitations of the engine.

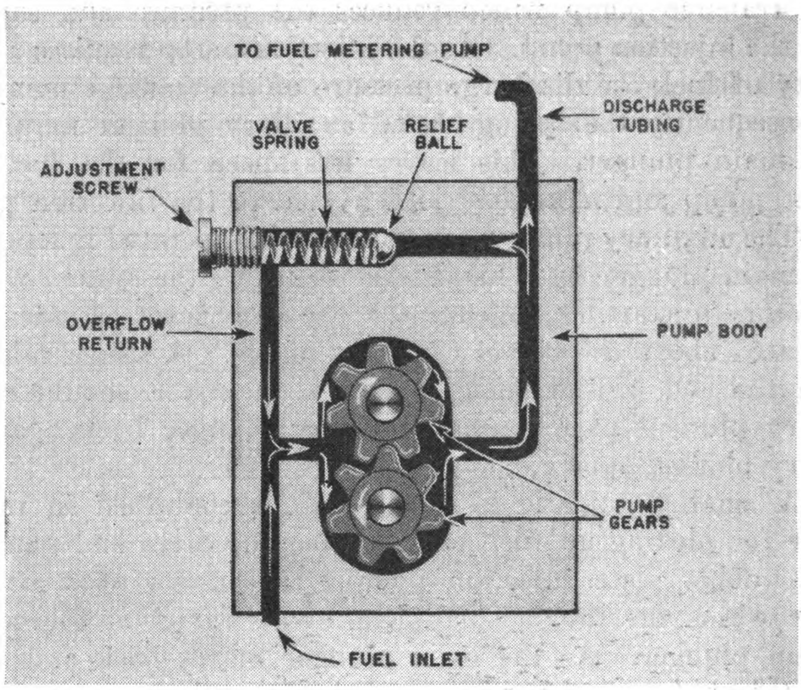



FIGURE 56.—Gear rotary transfer pump.

*b.* (1) The vane type rotary transfer pump, as illustrated in figure 57, is used on one two-stroke cycle engine. This pump has an integral steel rotor and shaft supported by a bushing at each end. The rotor is driven through gears by the engine and revolves in a cast iron housing. The housing bore is eccentric with the rotor shaft. Two sliding vanes are placed 180° apart in slots in the rotor and are expanded against the housing bore by coil springs in the slots. Two special seals on the pump shaft prevent leakage of fuel or lubricating oil. A drain hole between the two seals leads to the atmosphere.

(2) When the shaft is rotated, the vanes pick up fuel at the inlet port and carry it around the housing to the outlet side where the fuel is discharged. Pressure is produced by the wedging action of the

fuel as it is forced toward the outlet port by the vane. At the bottom of the pump body is a bypass valve consisting of a rubber diaphragm which is forced up by a spring loaded plunger, and closes the port between the discharge and intake passages of the pump. When the pump pressure exceeds 25 pounds per square inch, the bypass valve diaphragm and the plunger are forced downward, opening the bypass and some of the fuel oil is returned to the inlet side.

**43. Fuel filter.**—*a.* The importance of effective fuel filtering cannot be overemphasized. So important is this feature that filter

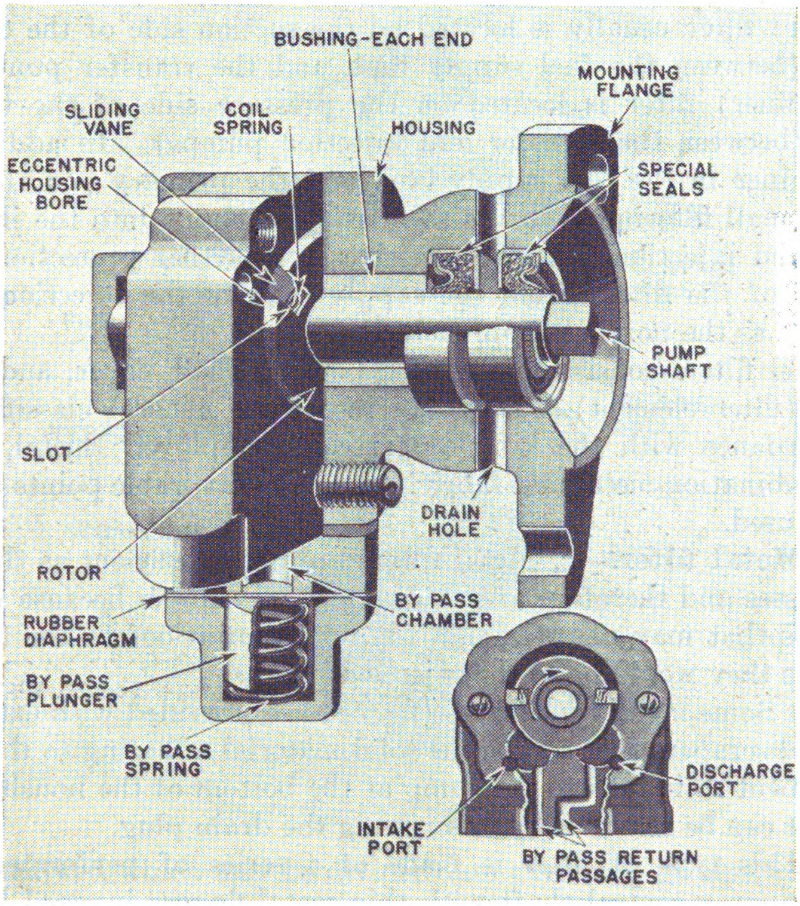



FIGURE 57.—Vane rotary transfer pump.

design has received as close consideration as any other portion of the fuel injection system and the selection of a suitable filtering medium has been the subject of the most careful experiments.

*b.* Most fuels hold a great deal of sediment in suspension, mucn of it fine abrasive particles quite capable of passing through the average filter. Abrasives may consist of material difficult to eliminate during the process of refining, or it may enter the fuel tank through careless

refueling. Whatever its source, it is imperative that means be provided to protect the fuel system from abrasives, which will ruin the fuel injection pump and nozzle.

*c.* Air carried into the pump by the fuel forms air pockets and is therefore extremely undesirable. Any air that enters must be given an opportunity to escape, preferably by passing the fuel through a suitable filter before it reaches the pump. Usually bleeder screws are provided on the filter for venting the air.

*d.* Most designs include at least two or more filters to filter adequately the fuel before it reaches the injection pump. The primary (coarser) filter usually is located on the suction side of the transfer pump (between the fuel supply tank and the transfer pump). A main (finer) filter is located on the pressure side of the transfer pump (between the transfer and injection pumps). In addition to the strainer in the fuel supply tank and the primary and the main filters, small filtering elements are frequently built into the injection pump and injection nozzles themselves for further protection. The fineness of the filters from the supply tank to the injection nozzle increases as the nozzle is approached.

*e.* Fuel filters consist chiefly of a housing shell, cover, and a cartridge (filter element). They fall into three general classifications in accordance with the kind of cartridge employed; metal, fabric, and combination metal and fabric. All have favorable points and are widely used.

**44. Metal filter.**—*a.* Metal filters are not as efficient as the other two classes and therefore are used as primary filters because the fine particles that may pass through are not as injurious to the transfer pump as they would be to the injection pump.

*b.* (1) Some metal type filters (fig. 58) are provided with externally operated scrapers that scrape the solid material adhering to the filtering element so it falls to the sump at the bottom of the housing shell where it can be removed by unscrewing the drain plug.

(2) This type of filter is made of a series of perforated disks placed upon a central shaft with thin metal fingers inserted between the disks. The fingers are held rigidly to the housing shell. Fuel enters the filter at the top inlet connection, flows between the disks to the perforations and up the central passage to the outlet connection at the top. Since the space between the disks is exceedingly small (about 0.0003 inch) dirt or foreign matter cannot pass through but is deposited between and on the outer rim of the disks. The set of disks may be rotated by the handle at the top so that the disks rub against the fingers and scrape off the dirt.

**45. Fabric filter.**—*a.* Fabric filters have an efficiency of approximately 90 percent when new and attain an efficiency of 100 percent after a few hours of operation. Because of their high degree of filtration, they are used principally as main filters for protecting the injection pump. Occasionally when they become clogged the increased fuel pressure may break the fabric, allowing unfiltered oil to flow to the injection pump. Several designs of fabric filters are

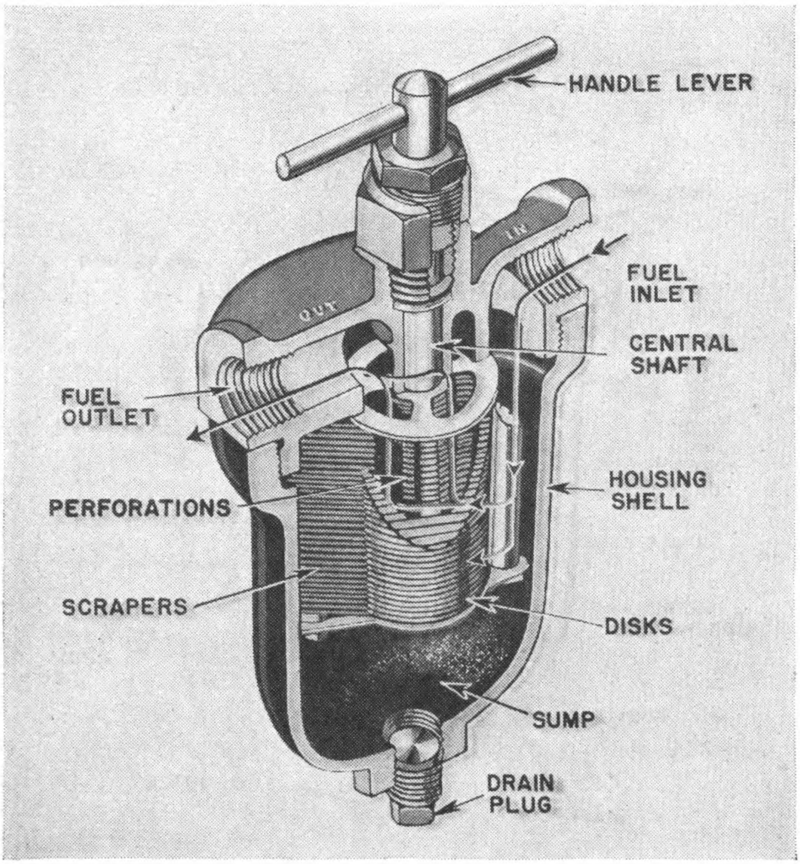



FIGURE 58.—Metal disk fuel filter.

on the market, which may be divided into two main groups, cloth and bag type filters.

*b.* Figure 59 shows a cross section of a simple form of cloth filter. The cartridge consists of a specially woven fabric wound on a brass cage which is stiffened inside by a metal screen tube. The unfiltered fuel enters through the inlet connection at the top and passes into the filter. The heavier particles of dirt and water settle in the sump of the housing shell. Any accumulation in the sump is easily drained by removing the drain plug. The fuel then passes through the fabric cartridge, where the finest traces of abrasives and dirt

are deposited on the outside surface. Lint from the fabric cartridge is deposited at the metal screen as the fuel passes through into the central space. The clean fuel flows through the bore in the central spindle and out into the outlet connection.

*c.* The construction of the felt cartridge filter shown in figure 60 differs from that of the cloth filter only in that a stack of felt elements are employed as the cartridge instead of the specially woven cloth fabric. These felt elements are of two grades (fine and medium texture) and are stacked alternately on the metal screen tube.

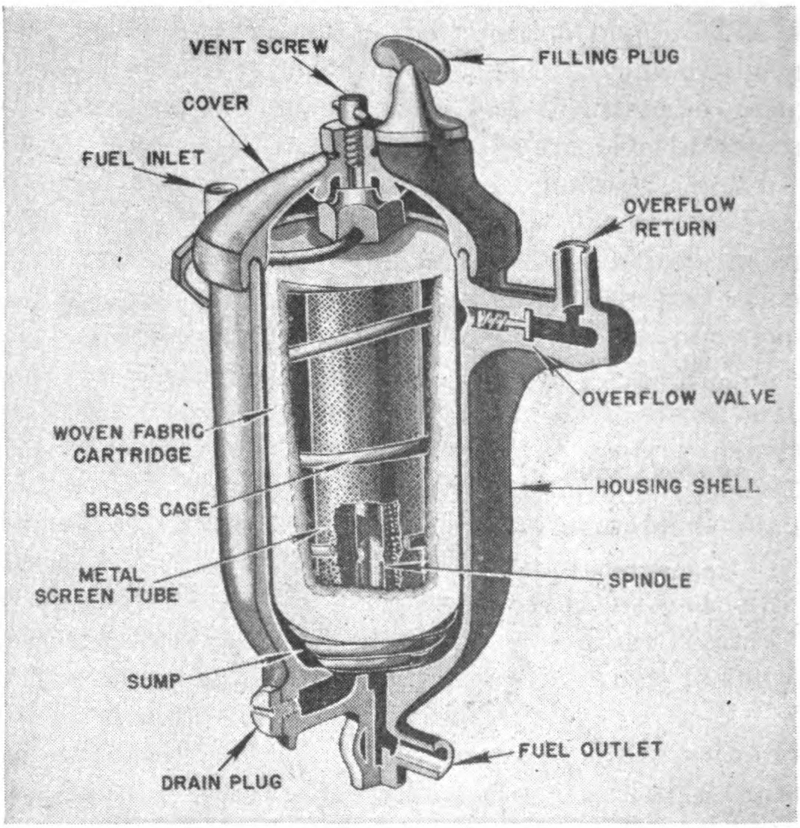



FIGURE 59.—Woven fabric cartridge fuel filter.

*d.* These filters have two outstanding features; first, uniform fuel flow with easy and effective venting of air, and second, automatic stoppage of the fuel flow when the housing cover and cartridge are removed. The flow of fuel stops the instant the gasket in the spring seat of the spring-loaded cartridge covers the bore in the spindle, thus preventing any unfiltered fuel from flowing through the outlet tubing and to the injection pump. These filters are built in several sizes in single and double arrangements.

*e.* A fuel filter with an extremely fine element is shown in figure 61. While its cartridge is not fabric, its construction and operation are similar to the cloth and felt filters. Cellulose material of several different types is used in successive layers. Metal screens retain the outer layer of cellulose. The two inner layers of cellulose are held against the inner screen of the cartridge by a vertical coil spring. This type of fuel filter is designed to remove particles as small as one four-millionth of an inch in diameter.

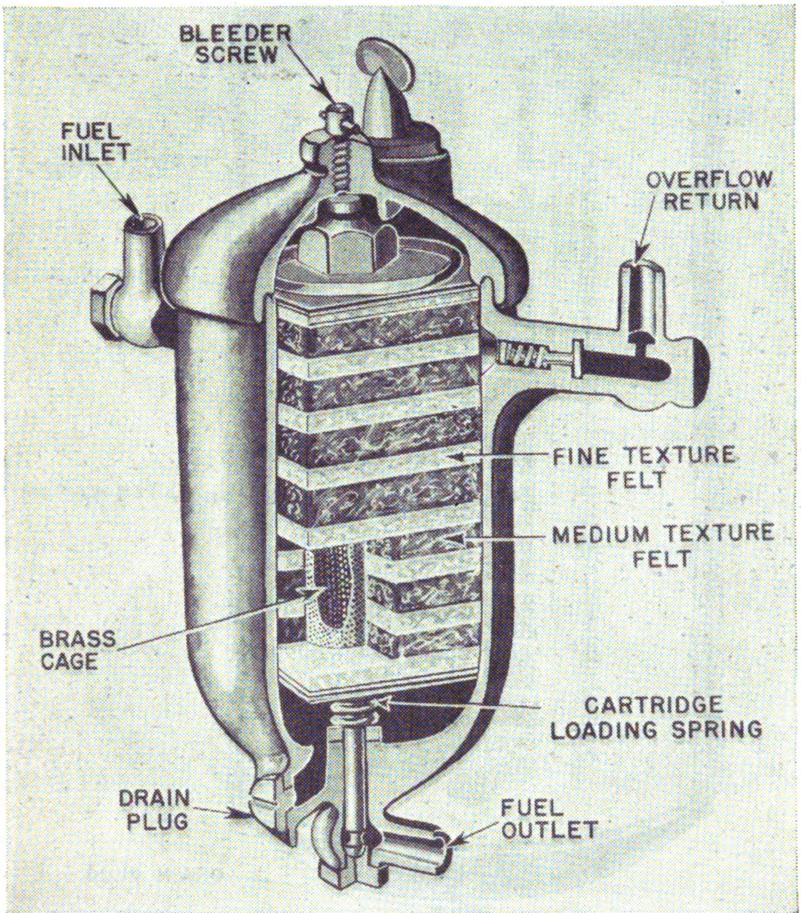



FIGURE 60.—Felt cartridge filter.

*f.* Figure 62 illustrates a common method of construction for bag filters. The bag of close mesh fiber is easily removable for cleaning or replacing when necessary. The bag fabric should be of woolen yarn as cotton bags may shed lint in the oil. It is held in an accordion-like shape by two coil springs. The bag fits around the metal screen tube and is secured at its open end to the housing cover by an adapter. Its operation is similar to that of the cloth type filter. Its accordion-like shape offers more filtering surface area than the other filter types described.

**46. Combination filter.**—Cloth and metal filters are often combined as a single unit to save space and to clean thoroughly the fuel. Air vent screws are often provided which should be opened about every 100 hours of operation to clear the filter of air.

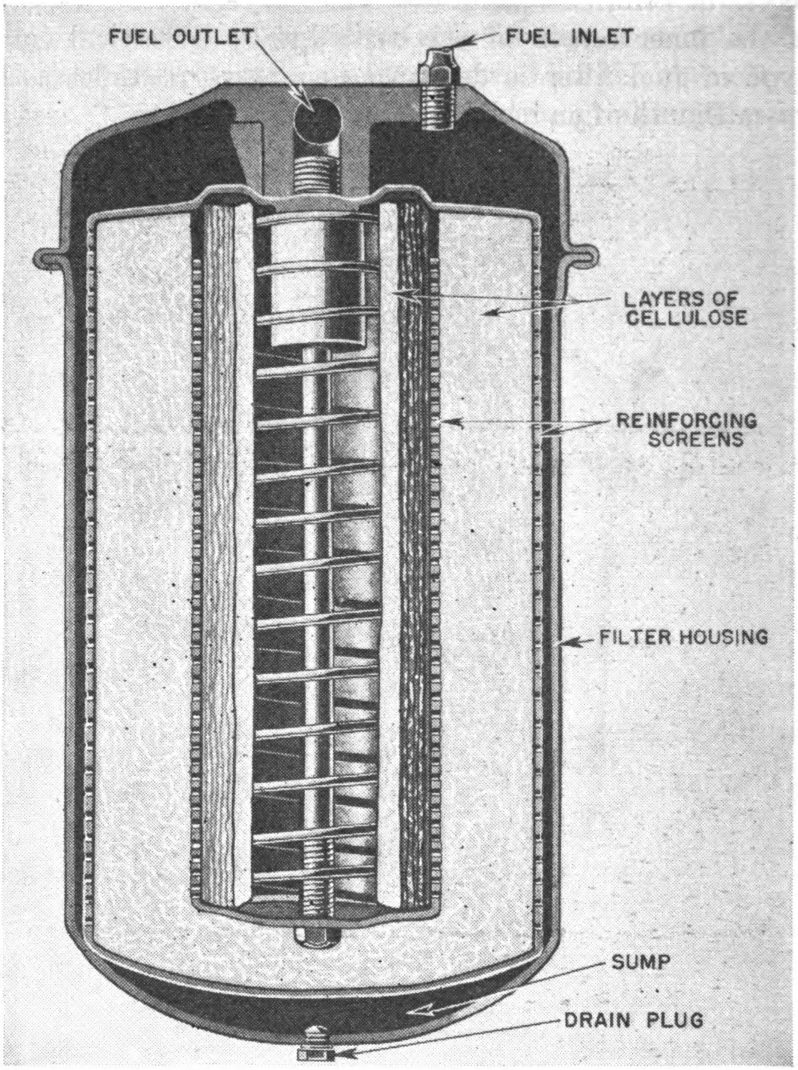



FIGURE 61.—Cellulose cartridge filter.

**47. Fuel tubing.**—Fuel pressures between the injection pump outlet and the injection nozzle inlet are sometimes as high as 10,000 pounds per square inch. The tubing must withstand this high pressure and the pounding effect caused by the rapid closing of the injection nozzle. A special seamless steel tubing is used between the injection pump and nozzle. The internal diameter must be uniform and smooth to insure easy flow of fuel. There should be sufficient

length of contact between tubing and fitting to insure strength. It is important that the several tubes to each cylinder in a multiple-cylinder engine are of equal length so that the fuel for each cylinder travels the same distance. To accomplish this it is necessary to coil some tubes.

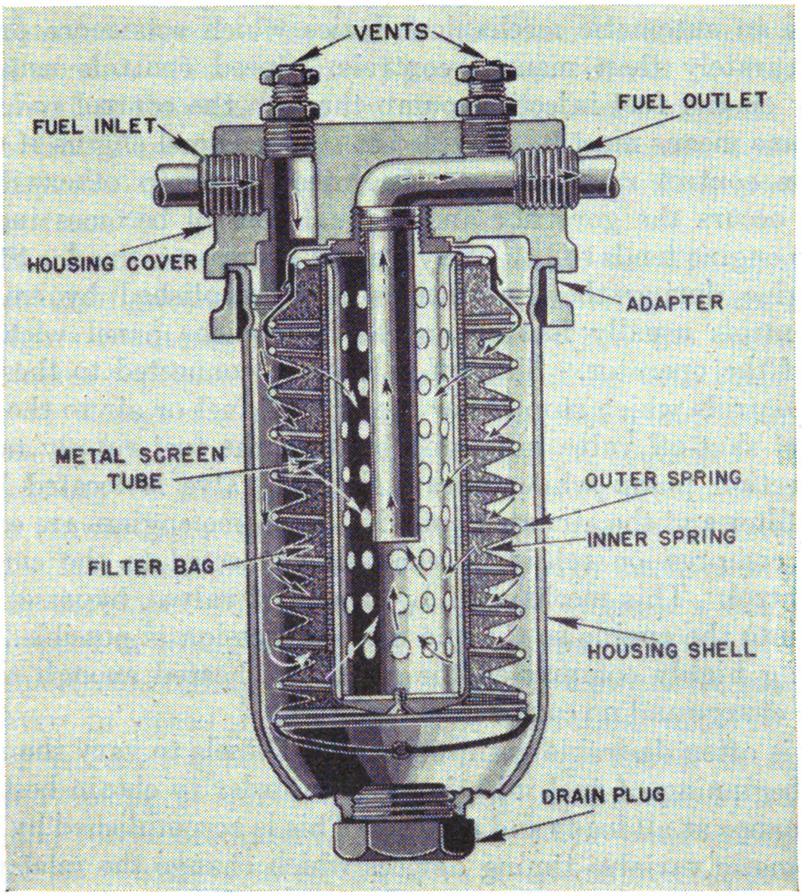



FIGURE 62.—Bag filter.

## SECTION VIII

## CONTROLS



**48. General.**—*a.* The Diesel engine, like gasoline engines, has the characteristic of increasing in speed as its load decreases. To pro-

tect it from racing (overspeeding) when the load decreases as well as from stalling (stopping) when the load becomes too great, a method of speed control is necessary. The controlling device regulates the quantity of fuel delivered by the injection pump to the engine cylinders and may be actuated manually (by a hand throttle or a foot accelerator) or automatically (by a governor). The governor is an automatic mechanical device which acts more promptly and accurately than manual controls. Speed controls usually act directly on the fuel injection pump through the control rod.

*b.* Some means must be provided to stop a Diesel engine if the fuel injection control rack jams or the injection pump otherwise fails. If this occurs the governor and manual control becomes ineffective and the engine tends to run away upon a decrease in load. Stopping the engine during these conditions is accomplished by emergency stop controls usually located on the instrument panel within easy reach of the operator. Shut-off valves are connected to these emergency controls which stop either the flow of fuel or air to the engine. The fuel shut-off valve is located between the fuel supply tank and the injection pump while the air shut-off valve is located between the air filter and the air intake manifold. Some engines are equipped with a compression release mechanism connected to the emergency stop control. This mechanism, by means of valves, bypasses the air drawn into the engine so that no air compression is possible. Without being highly compressed the air is not heated enough to ignite the fuel charge and no combustion occurs.

*c.* It is often desirable with high speed Diesels to vary the moment of the beginning of fuel injection also in order to obtain best engine performance at all loads and speeds. This is accomplished by manual or automatic variable timing devices which change the relative position of the fuel injection pump shaft to that of the engine crankshaft.

**49. Governor.**—*a.* The Diesel engine governor is usually mounted on the injection pump. The amount of speed change required to actuate the governor is termed its "sluggishness." It is due to friction in the governor and the friction and inertia of the control linkage and injection pump parts. If the friction is great, it is plain that the engine speed will change considerably before the governor overcomes the frictional resistance. Conversely, if the friction is low and the parts are light in weight the governor will lack stability and move violently from one extreme to another. In practice this overcompensating action is called "hunting" and is given in percentage of closeness of speed regulation.

*b.* Governors may be classified according to purpose as follows:

(1) *Minimum-maximum speed.*—These governors only control idling and maximum speeds. Intermediate speeds are controlled by the operator.

(2) *Adjustable speed.*—These governors control the engine speed at any desired setting.

(3) *Constant speed.*—For electric generator or constant speed industrial service. Constant speed governors will not be discussed in this manual as they are used mainly on stationary engines.

*c.* Governors are divided into mechanical, pneumatic, and hydraulic. They are for the most part lubricated by their own splash oiling systems.

**50. Mechanical (centrifugal) governor.**—*a.* The operation of the mechanical governor is based upon the centrifugal force of rotating weights counterbalanced by springs. When the speed of the engine increases, the weights fly outward pulling with them suitable linkage to change the setting of the injection pump control rod. When the weights are at their highest position (outward) the minimum quantity of fuel is injected. When they are in their lowest position (inward) the maximum quantity of fuel is delivered.

*b.* (1) The minimum-maximum speed type of mechanical governor has been developed for automotive Diesel engines which tend to vary in speed at idling or no-load. This type of governor prevents the engine from stalling as well as racing but otherwise has no part whatsoever in speed regulation. The operation of this type of governor is based upon two pairs of springs shown in figure 63. The outer spring is soft and thus easily compressed by the small, centrifugal forces produced at low speeds. The inner spring is stiff and requires considerable force before it is compressed, so that the engine speed must be high before the centrifugal force of the flyweights is sufficient to overcome the spring force. The outer spring controls the minimum quantity of fuel fed to the engine cylinder while the inner spring controls the maximum quantity of fuel delivered.

(2) The closeness of speed regulation for this type of governor is 8 to 10 percent. The minimum idling speed at which it can still control the quantity of fuel is an engine speed corresponding to about 200 r. p. m. of the injection pump. An engine speed corresponding to an injection pump speed of 1,300 r. p. m. represents about the maximum speed at which it will function. Two pairs of flyweights are used for pump speeds from 1,300 to 2,000 r. p. m. On automotive Diesels with injection pumps having a steep camshaft, large diameter

plungers and high nozzle opening pressures, overrunning clutches are sometimes used to transmit the rotation of the pump shaft to the flyweights of the governor. This clutch permits the flyweights to rotate independently (by inertia) when the injection pump shaft speed decreases suddenly and relieves the governor of severe torsional stresses induced by rapid deceleration of the engine.

*c.* Figure 64 illustrates the construction of a minimum-maximum speed governor employed on a two-stroke cycle Diesel engine. It consists of three main assemblies: the flyweights, the control mecha-

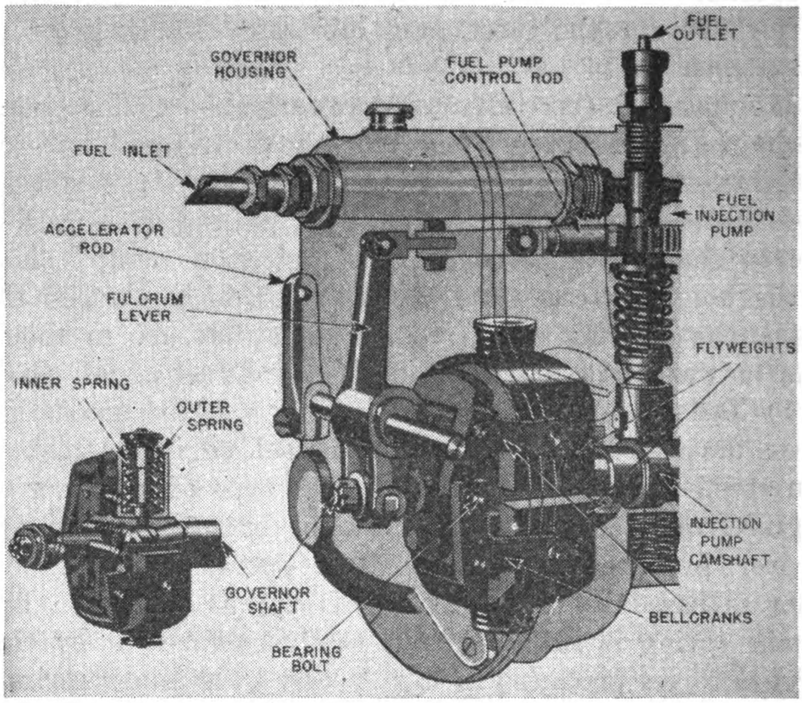



FIGURE 63.—Minimum-maximum mechanical governor.

nism, and the cover. The governor shaft carries two sets of flyweights and is driven by the blower of the two-stroke cycle engine. The control mechanism transmits the motion of the flyweights to the rack controlling the unit injectors. It consists of a vertical shaft with a fork or yoke fixed at its lower end and high and low speed governor springs with suitable adjustments at the upper end. The cover assembly carries the stop lever and the throttle control lever, and closes the top of the control mechanism housing.

*d.* (1) The adjustable speed mechanical governor (fig. 65) maintains any desired engine speed regardless of the load applied to the engine, unless of course the load is beyond the capacity of the engine. The closeness of regulation is within 8 to 10 percent.

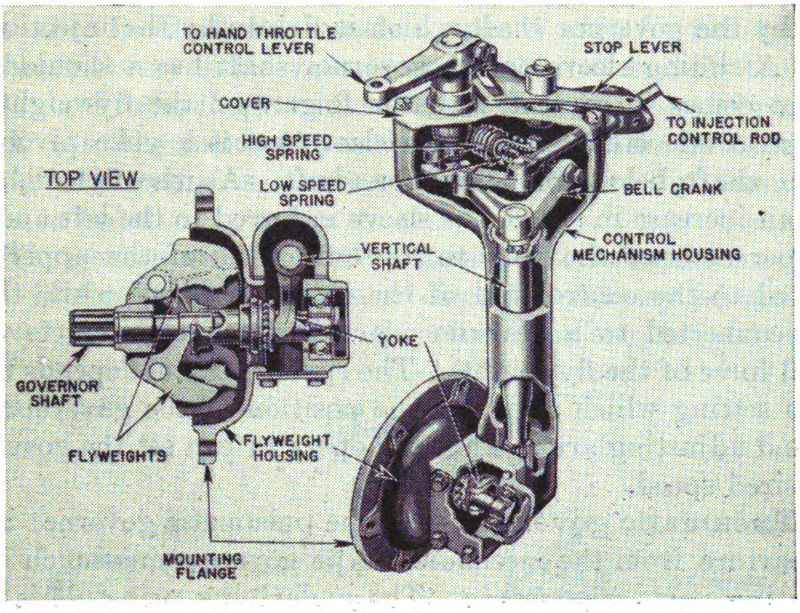



FIGURE 64.—Another type of minimum-maximum mechanical governor.

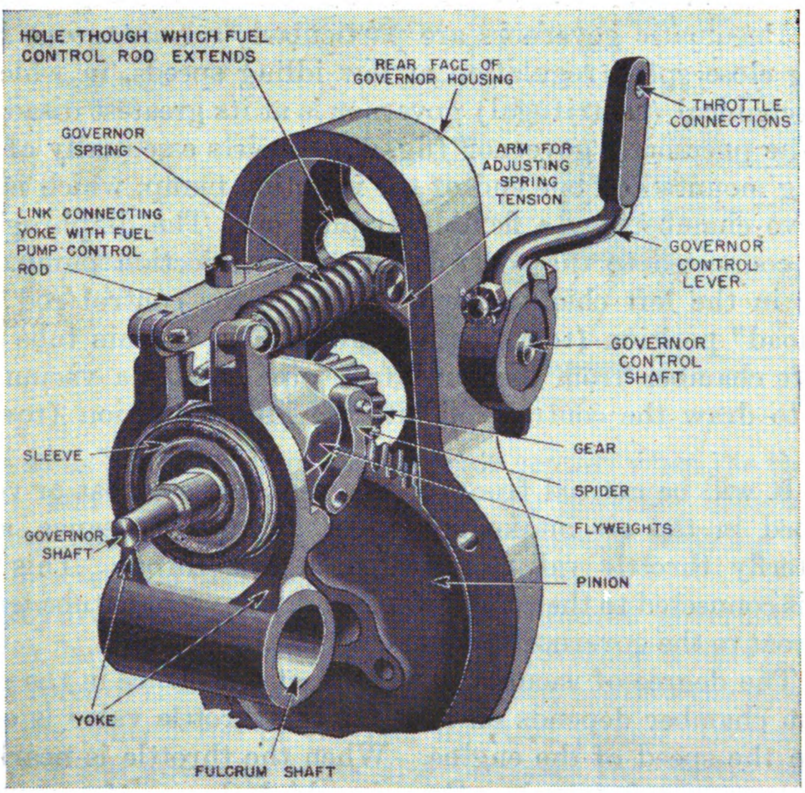



FIGURE 65.—Adjustable speed mechanical governor.

(2) The two flyweights are hinged to a spider mounted on and driven by the governor shaft which is driven by the injection pump shaft. A sliding sleeve on the governor shaft has a shoulder at one end that comes in contact with the fingers on the flyweights. The shoulder at the other end of the sleeve meets a yoke pivoted on a fulcrum shaft below the governor shaft. As the flyweights open due to an increase in speed, the sleeve is forced to the left and swings the upper ends of the yoke to the left. One of the upper ends is connected to the control rod of the injection pump while the other end is connected to a governor spring which counteracts the centrifugal force of the flyweights. The spring tension depends upon the throttle setting which regulates the position of the governor control shaft and adjusting arm. Thus the operator can set the governor for any desired speed.

**51. Pneumatic governor.**—*a.* The pneumatic governor is a radical departure from the mechanical type governor inasmuch as it has no rotating parts whatsoever. The underlying principle is that air passing through a pipe tends to create a vacuum in another smaller pipe, entering it at a right angle. The amount of vacuum created depends upon the velocity of the air passing through the larger pipe. Pneumatic governors are particularly advantageous in maintaining close speed regulation at low idling speeds, in which range the mechanical (centrifugal) governor is at its greatest disadvantage.

*b.* The pneumatic governor (fig. 66) consists essentially of a metal housing mounted on one end of the injection pump, which is divided into two chambers by a flexible diaphragm. The diaphragm is directly connected to the control rod of the injection pump. A coil spring in the left chamber tends to force the control rod into the "full load" position (toward the right). The vacuum tube entering the left chamber from the air intake pipe creates a vacuum which tends to draw the control rod into the idling position (toward the left).

(1) It will be noticed from the diagram that a throat or venturi is provided in the air intake pipe close to the air cleaner, and that a butterfly throttle valve is located in this throat. This throttle valve is connected to the accelerator pedal. A vacuum tube leads from the throat to the governor vacuum chamber.

(2) The degree of vacuum in the throat and hence in the governor vacuum chamber depends on how far the throttle valve is open and also on the speed of the engine. When the throttle is nearly closed while the engine is running, there is a high degree of vacuum in the throat, and the high vacuum in the vacuum chamber will draw the

control rod of the injection pump toward the left (idling position). On the other hand, if the throttle is opened wide for full load operation, there is very little vacuum in the throat and in the vacuum chamber, and the coil spring then forces the pump control rod toward the right into the full load position. This explains how the fuel delivery of the pump is increased and decreased by means of the accelerator pedal.

(3) The governor naturally is sensitive also to variations in engine speed. If the speed increases, so does the velocity of air through the throat, with the result that the vacuum in the throat is increased

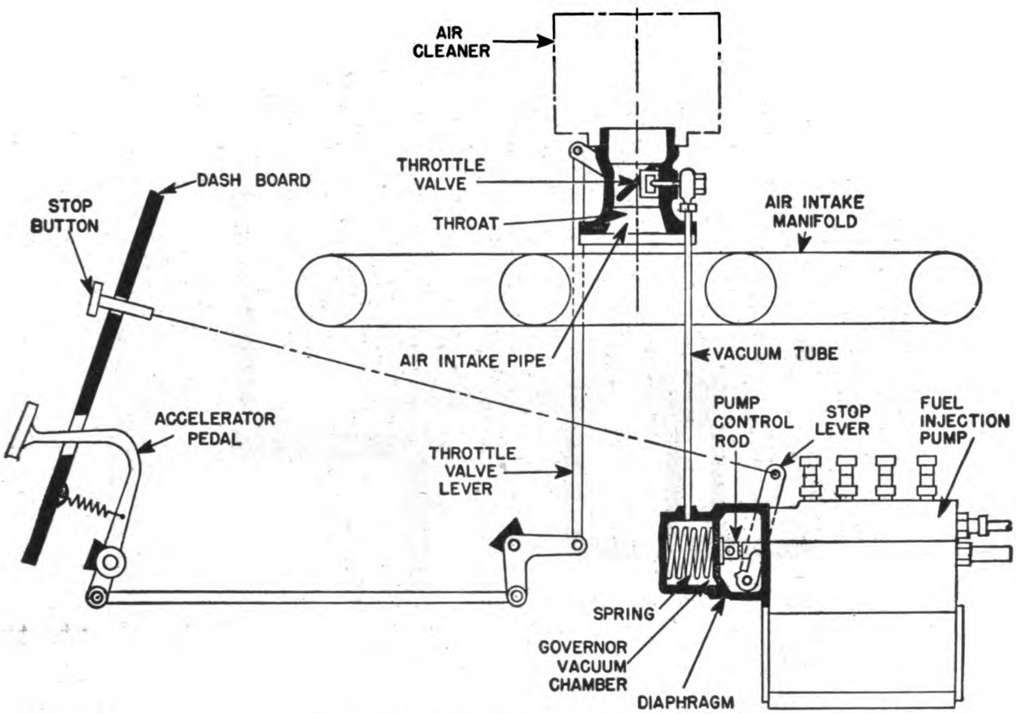



FIGURE 66.—Pneumatic governor.

(on the same principle as in a carburetor venturi when the throttle is opened), and the increased vacuum in the governor chamber pulls the pump control rod toward the left, thereby reducing the fuel charge injected and decreasing the speed again.

**52. Hydraulic governor.**—*a.* The hydraulic governor is used mainly on large engines where, unless the governor is heavy, the centrifugal force of the flyweights is not sufficient to allow the governor to actuate the control rod of the fuel injection pump. Increasing the weights of the governor parts also increases the inertia effects so that the governor becomes sluggish in responding to engine speed changes. To overcome this difficulty a servo-motor is employed to

provide power for moving the injection pump control rod while the governor regulates only the valves of the servo-motor.

*b*. (1) Oil from the engine lubricating system is admitted under pressure to an auxiliary oil pump in the governor. The auxiliary oil pump furnishes the necessary oil pressure to actuate the governor mechanism (see fig. 67). In this governor, fuel is decreased by action of a fuel rod spring and increased by the opposing action of a hydraulic servo-cylinder. The pilot valve, which controls the oil admitted to the servo-cylinder, is controlled by the flyweights of the

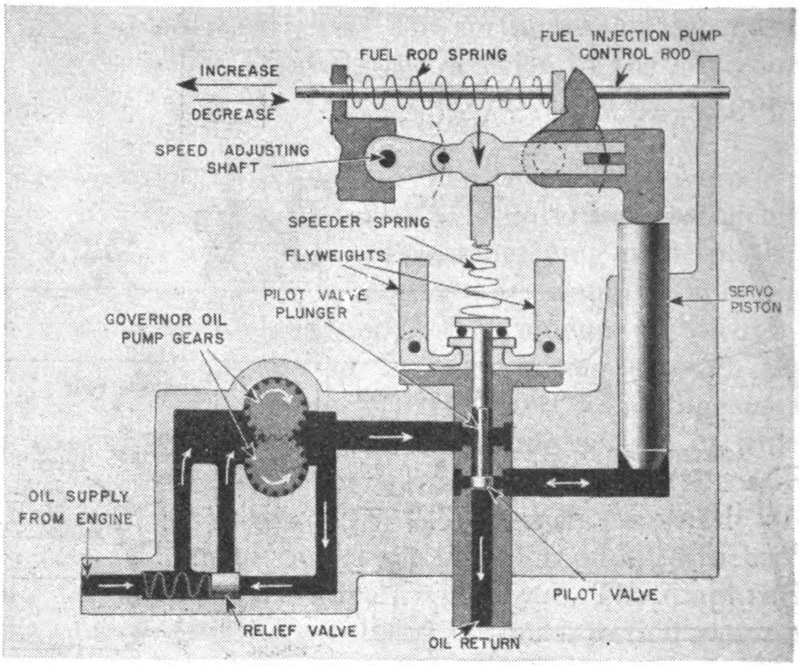



FIGURE 67.—Hydraulic governor.

governor. These are mounted on a vertical shaft and driven through gears from the engine crankshaft. The centrifugal force of the flyweights in rotation is opposed by a so-called "speeder spring," the compression of which determines the speed at which the governor will control the engine. The compression of the speeder spring is varied by the hand knob on the instrument panel.

(2) If the engine speed drops below that corresponding to the setting of the compression speeder spring, the flyweights fall inward and lower the pilot valve plunger. Oil is admitted to the servo-cylinder, which raises the piston and increases the fuel supply. If the engine speed increases above that corresponding to the setting of the speeder spring, the flyweights fly outward and raise the pilot valve plunger. This cuts off the oil supply to the servo-cylinder,

the servo piston drops, and the fuel supply is decreased. Under balanced conditions, the pilot valve nearly closes its ports, passing only enough oil to supply leakage and maintain the piston in a given position.

**53. Variable timing device.**—*a.* The manually operated timing device shown in figure 68 consists of a housing containing a bushing with an externally cut spline which is keyed to the extension of the

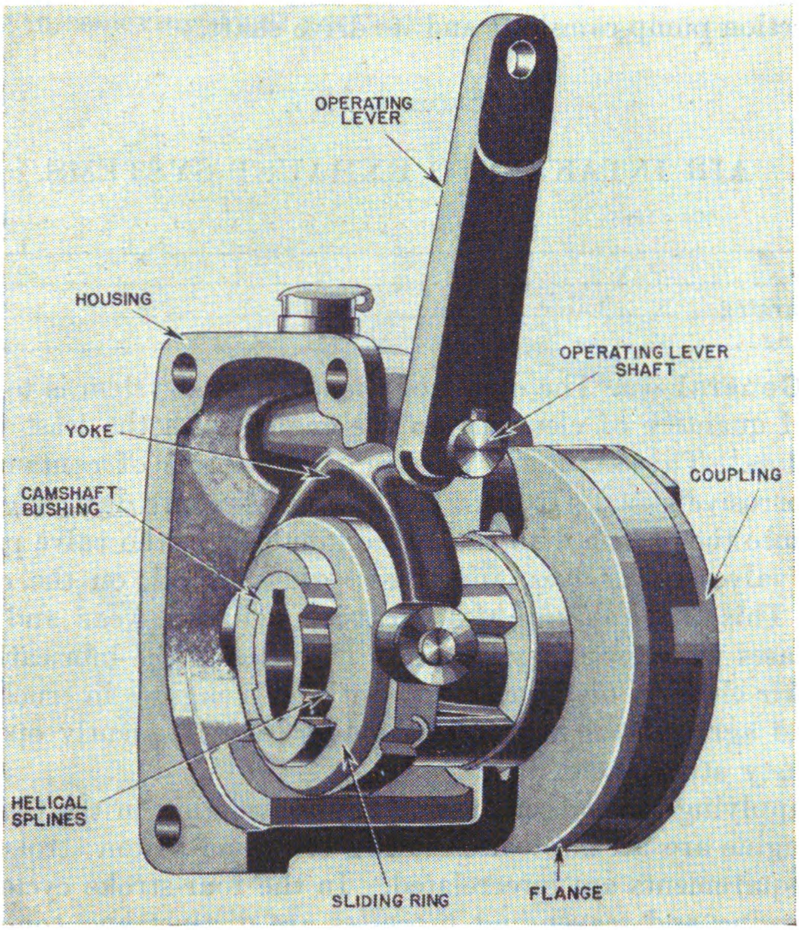



FIGURE 68.—Manually operated fuel injection timing device.

injection pump camshaft, and an internally splined sliding ring which fits over the bushing and is connected by a yoke to the operating lever. A flange is connected on one end to the sliding ring and on its other side to a coupling driven by the injection pump drive shaft. When the operating lever is moved, the sliding ring is shifted longitudinally. The action of the helical splines of the sliding ring and camshaft bushing rotates the injection pump camshaft slightly relative to the injection pump drive shaft. This advances or retards

the timing of the injection pump with relation to the top dead center position of the engine's pistons. The range of adjustment is from 8° to 12° of camshaft rotation.

*b*. The load on automotive engines is not always proportional to the speed, which makes automatic timing devices actuated by speed changes more suitable than manual ones. Automatic timing devices differ from manual devices only in that they utilize the centrifugal force of flyweights to change the angular relationship between the injection pump camshaft and its drive shaft.

## Section IX

## AIR INTAKE AND EXHAUST SYSTEMS



**54. General.**—*a*. The object of the air intake system is to get the required quantity of clean air to the engine with the least possible power loss. This air must be pure, that is, free of contamination from corrosive gases. It must be clean because any dust or grit that passes into the engine with the air accumulates in the valve passages, on the valves themselves, and most serious of all, on the cylinder walls. This inevitably causes excessive cylinder wear and in extreme cases will cause deposits and difficulties in the lubricating system. Air cleaners or filters are essential for engines in trucks, tractors, and agricultural machinery because they frequently operate in very dusty atmosphere.

*b*. Supplying air for combustion and scavenging in the two-stroke cycle engine are accomplished during the same piston stroke, hence these requirements are interrelated. In the four-stroke cycle engine the charging and scavenging processes are distinct and complete in themselves.

**55. Air filter.**—*a*. There are three types of air filters or cleaners used on Diesel engines to supply cleaned air to the cylinder: the centrifugal, the dry, and the wet (oil bath). The first depends upon centrifugal force for separating the dirt and air, while the latter two depend upon straining or filtering elements.

*b*. The centrifugal air filter is shown in figure 69. Dusty air enters through the inclined slots in the top of the hood and receives a whirling motion from vanes fastened to a conical cover, which in

turn is fastened to the same shaft as the wheel. The wheel (fan) is kept revolving by the inrushing air. As the dusty air is whirled by the vanes, the centrifugal force thus created throws all foreign particles suspended in the air to the outer walls of the casing where they are ejected through the circular opening. The advantages of this type of cleaner are low resistance to air flow, requires no cleaning and little attention except occasional oiling, is small in size and inexpensive to operate. It is seldom used because of its low efficiency in removing small particles.

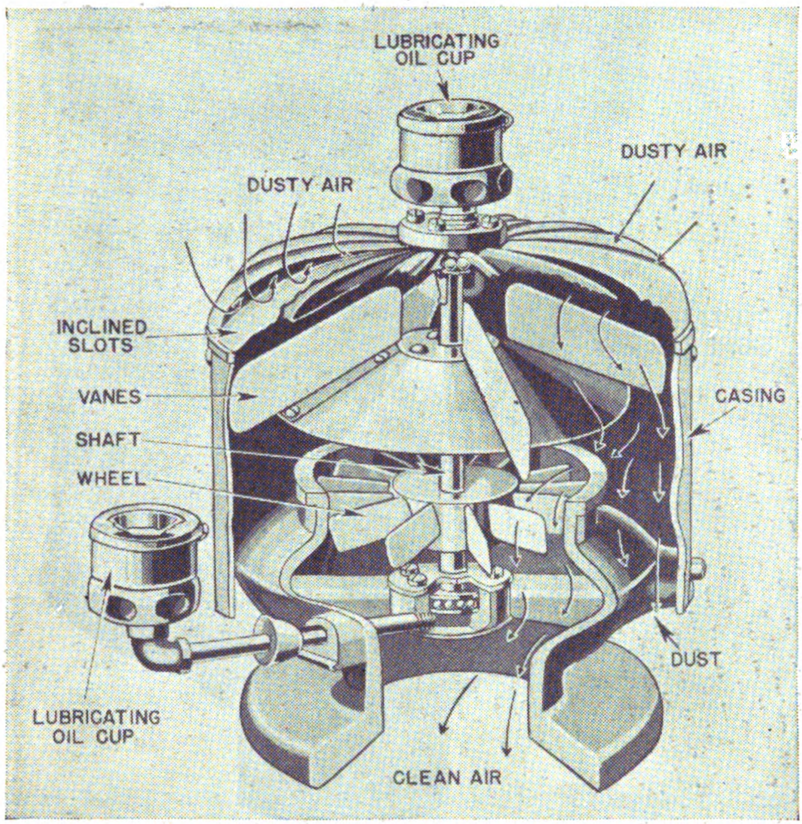



FIGURE 69.—Centrifugal air filter.

*c.* The dry air filter depends upon fabric stretched over metal forms or wire screens to strain the air. A typical filter of this type is shown in figure 70. It consists of several layers of screens constructed of round, smooth wire woven into square, biased, and crimped designs. The density of these screens increases with succeeding screens. Thus lint and coarse dust particles are caught on the outside and the finer particles are caught on the inside.

*d.* The wet air filter (often called an oil bath air cleaner) is the most efficient of the three types mentioned and therefore is used ex-

tensively. The volume of air is divided by the filtering element into many small currents which are baffled through filters. The dust is thrown on the oiled surfaces where it sticks. This cleaner is built in a variety of forms.

(1) In figure 71 the incoming air is induced to whirl or roll, giving up some of its dirt. Additional dust is washed out when the air

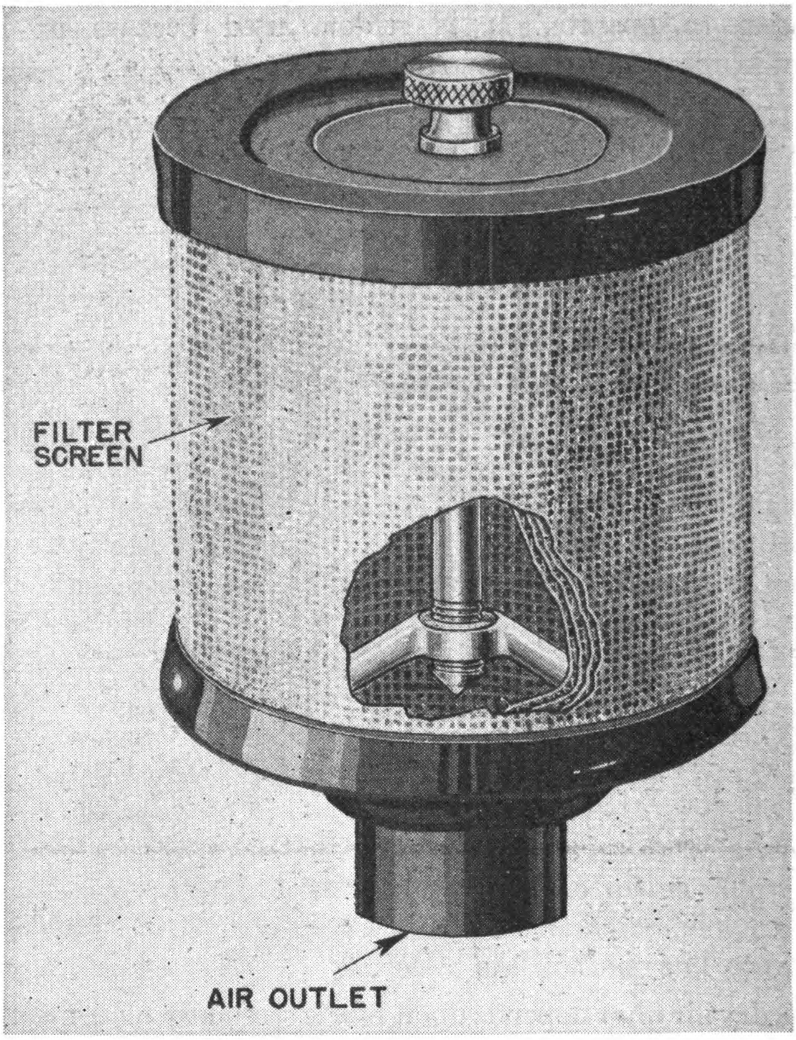



FIGURE 70.—Dry air filter.

comes in contact with the oil bath. As the air passes through the filter screens it carries oil up to them, thus being cleaned and producing a self-washing effect on the screen at the same time. The dirt collects in the bottom of the bath.

(2) The cutaway view in figure 72 shows another popular form of wet type filter which also uses the centrifugal principle of dust

separation. The air enters through the center air intake, whose lower end is submerged below the oil level. The sudden reversal of air flow direction (at the bottom) separates a large portion of the dust which drops to the bottom of the cup. All the air is washed as it passes through the oil in the cup. Oil is carried up as a mist into the screen element, which separates the oil from the air and returns the oil to its reservoir. The oil cup or pan containing the oil is easily removed by loosening the clamp shown in the illustration. This provides a quick method of replenishing the filter with clean oil when necessary. Figure 73 shows a typical ar-

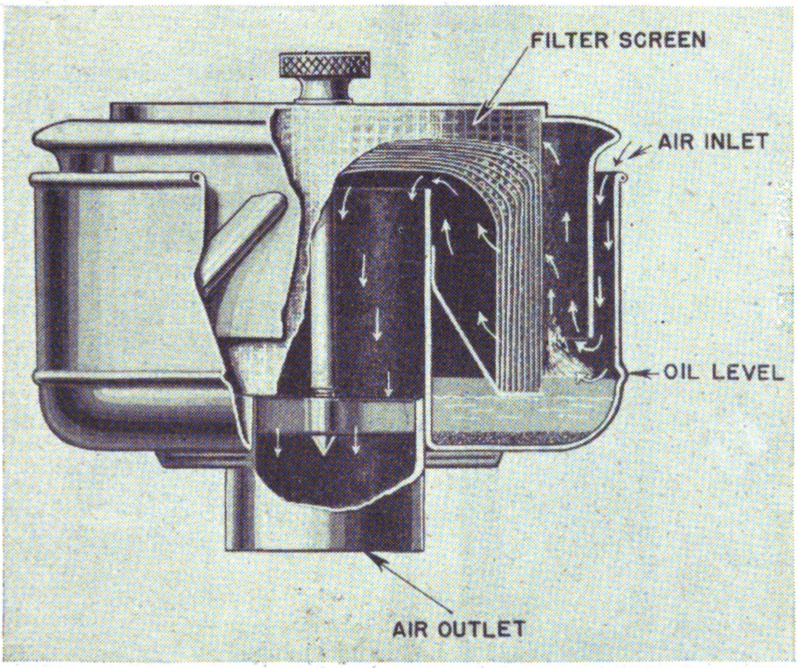



FIGURE 71.—Wet (oil bath) air filter.

rangement for mounting this type of air filter on a Diesel truck engine.

**56. Supercharging.**—*a.* It is possible to obtain a greater power output from an engine by increasing the quantity of air supplied to the cylinders. This increased amount of air requires a correspondingly greater quantity of fuel and therefore a higher average cylinder pressure, resulting in a greater power output.

*b.* The supercharger is merely an auxiliary air pump or compressor used to pack more air into the cylinders than is normally drawn in during the suction stroke of the engine. It has three useful applications.

(1) For four-stroke cycle engines in which the engine speed is so high that the natural suction stroke will not have time to draw enough air into the cylinders to maintain maximum power of the engine.

(2) For aviation engines where, due to service in rarefied air at high altitudes, the quantity of air received by the cylinders drops off considerably with a consequent loss in power.

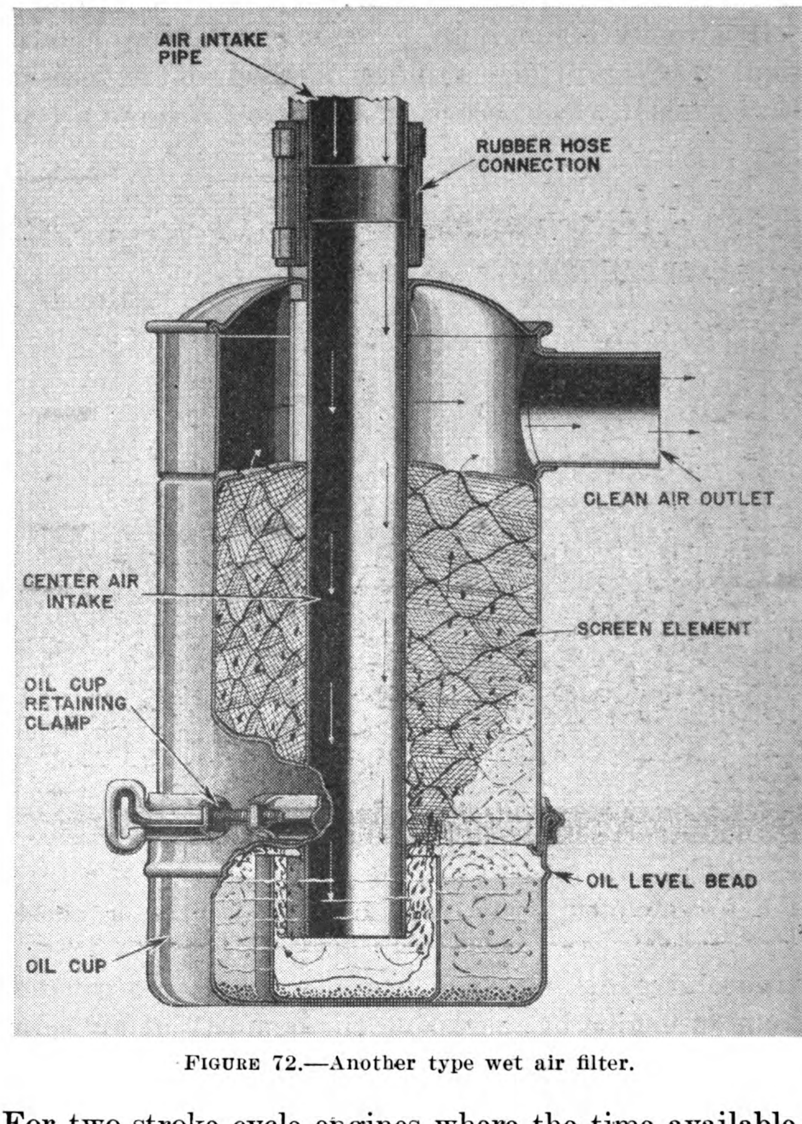



FIGURE 72.—Another type wet air filter.

(3) For two-stroke cycle engines where the time available for the suction stroke is limited.

*c.* Most aviation and two-stroke cycle engines require superchargers. There is a trend toward a greater use of superchargers on four-stroke cycle Diesel engines.

**57. Scavenging.**—*a.* In four-stroke cycle engines scavenging is a simple process as the complete exhaust stroke is devoted to expelling the burnt gases from the engine cylinders. In the two-stroke cycle engine other means must be provided to introduce a charge of air into the cylinder, both to clear it of burned gases from the previous combustion and to supply the air charge for the next combustion period. These scavenging and charging processes are combined in one movement of the air since the incoming fresh air displaces the exhaust gases in the cylinders. In practice the incoming air and the exhaust gases intermingle slightly and some of the fresh air is swept through the cylinder and out with the exhaust.

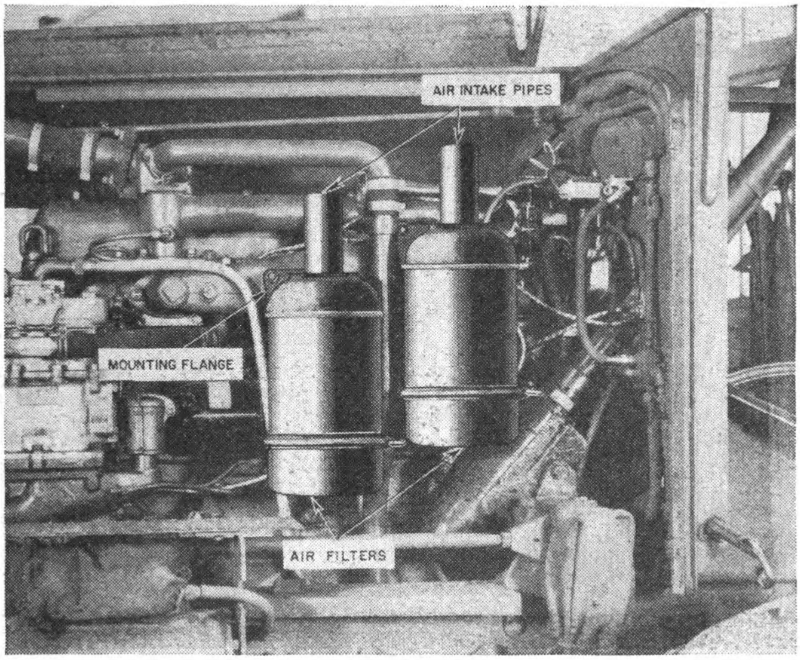



FIGURE 73.—Wet air filter installed.

*b.* Crankcase compression scavenging is the simplest arrangement. On the upward stroke of the piston, air from the atmosphere is drawn through automatic valves in the crankcase, and at the end of the power stroke this air is compressed and forced through ports in the cylinder wall. The automatic air inlet valves consist of flaps or disks which cover ports in the crankcase; when the piston is on its compression stroke, the flaps are drawn off their seats, thus allowing the air to flow through the ports. This method of scavenging requires a heavier engine frame construction and is therefore found only on stationary and marine engines.

*c.* In the separate scavenging method the air is compressed in a scavenging compressor or blower, which may be driven by the engine being scavenged. Separate scavenging may be accomplished by a reciprocating piston, rotary vane, or gear type compressors. However, the difficulty encountered with compressor valves at high speeds and with pulsations in the air supply has led manufacturers of automotive Diesel engines to favor the gear or blower type of scavenging compressor.

(1) The blower type of compressor offers the advantage of having no valves. Furthermore, if it is driven by the engine served, it re-

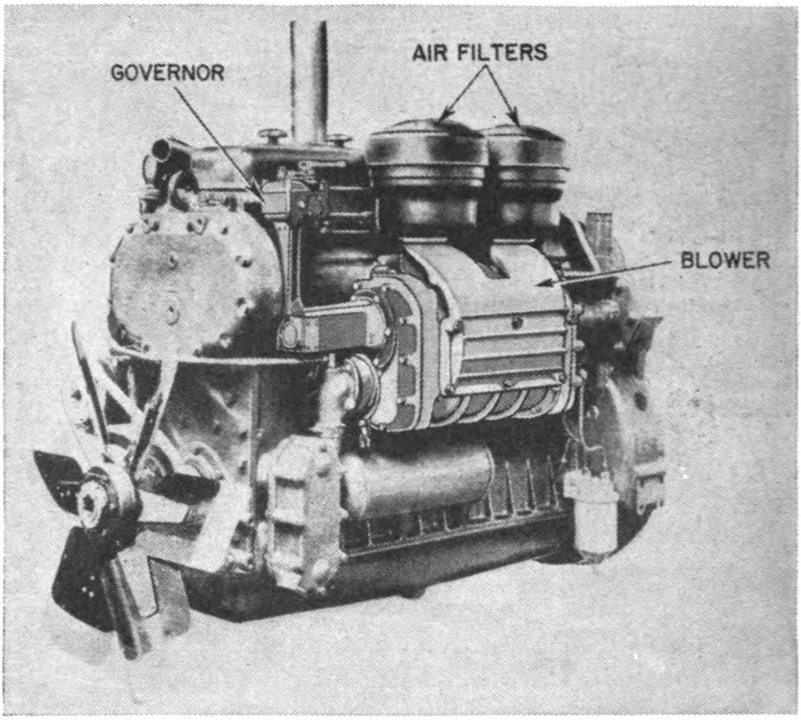



FIGURE 74.—Two-stroke cycle engine blower installation.

sponds immediately to any speed variations. The blowers are frequently built into the engine structure to form a compact and easily serviced unit. Figure 74 shows a typical two-stroke cycle automotive Diesel engine having the blower mounted at the side.

(2) Figure 75 illustrates the flow of air through the two-stroke cycle engine. The small ports around the lower portion of the cylinder sleeve are at a slight angle which imparts a rotary motion to the air as it enters the cylinder. This rotation persists throughout the compression stroke and not only insures thorough scavenging of the cylinder, but also improves combustion because of the turbulence of the fresh air charge at the time of fuel injection. The operation of the

blower is similar to that of the gear type oil pump. To provide continuous and uniform displacement of air, the rotor lobes are twisted or helical in form. The continuous discharge of fresh air from the blower creates an air pressure of about 7 pounds per square inch in the air chamber at maximum engine speed.

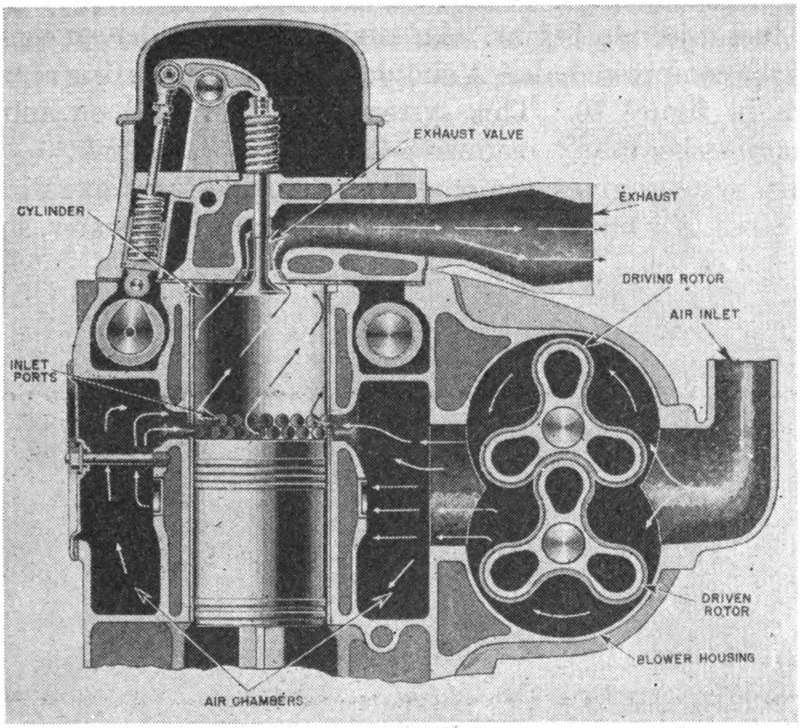



FIGURE 75.—Path of air through blower on two-stroke cycle engine.

## SECTION X

## STARTING SYSTEM



**58. General.**—The entire service reliability of a Diesel engine rests in most cases upon the starting system. Diesel engines require more power for starting than gasoline engines of the same size because of their heavier construction, much higher compression, and the necessity for very much higher engine cranking speed to reduce the heat lost in the combustion chamber during compression. At atmospheric temperatures below freezing, starting is especially difficult as the heat from the compressed air charge may be lost so rapidly that ignition

does not occur unless special provision is made. Diesel engines are started by air, by a small gasoline engine, by an electrical system, or by using special characteristics of the Diesel engine itself.

**59. Air.**—*a.* The compressed air is admitted to the Diesel engine cylinders through special starting valves to actuate the pistons. When sufficient engine speed is developed, the starting air supply is cut off and the fuel injection begins. An auxiliary engine driven compressor supplies the compressed air. A simple diagram illustrating air starting is shown in figure 76. This system is seldom used on automotive Diesel engines because it requires a large air storage tank.

*b.* This system gives comparatively trouble-free operation with regular care. Air tanks, which accumulate condensed water, should be

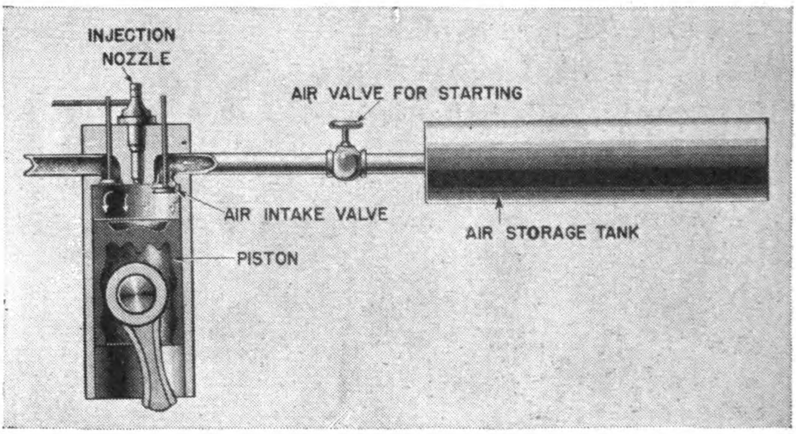



FIGURE 76.—Air starter system.

drained at regular intervals to prevent water from entering the engine cylinders. Lubricating oil from the compressor evaporates to some extent and goes into the air tank. If the oil vapor becomes dense enough a violent explosion will result.

**60. Gasoline engine.**—In this system a small auxiliary gasoline engine (fig. 77) is used for cranking the Diesel engine. This starter is usually a one- or two-cylinder engine permanently mounted on the side or rear of the Diesel engine frame. It is easily started by hand cranking and drives the Diesel engine flywheel either through a conventional Bendix drive or by a belt. Arrangements are usually made for circulating the hot exhaust gases from this engine through the intake manifold and through the cylinders of the Diesel engine. The cooling water of the starting engine is also circulated through the water jackets of the main engine. Thus the Diesel engine is quickly preheated, which facilitates starting in cold weather. The disadvantages of this type of starting are that it tends to make the power unit bulky,

increases the initial cost of the unit, and requires the servicing of an additional engine.

**61. Electric.**—*a.* The increased use of Diesel engines has stimulated an improvement of electrical starting systems, particularly those designed for operating at temperatures below freezing. While these systems are similar to the starting equipment on ordinary automobile engines the higher compression pressure of Diesels requires a much greater starting torque, or force. A 6-volt system is ample for starting

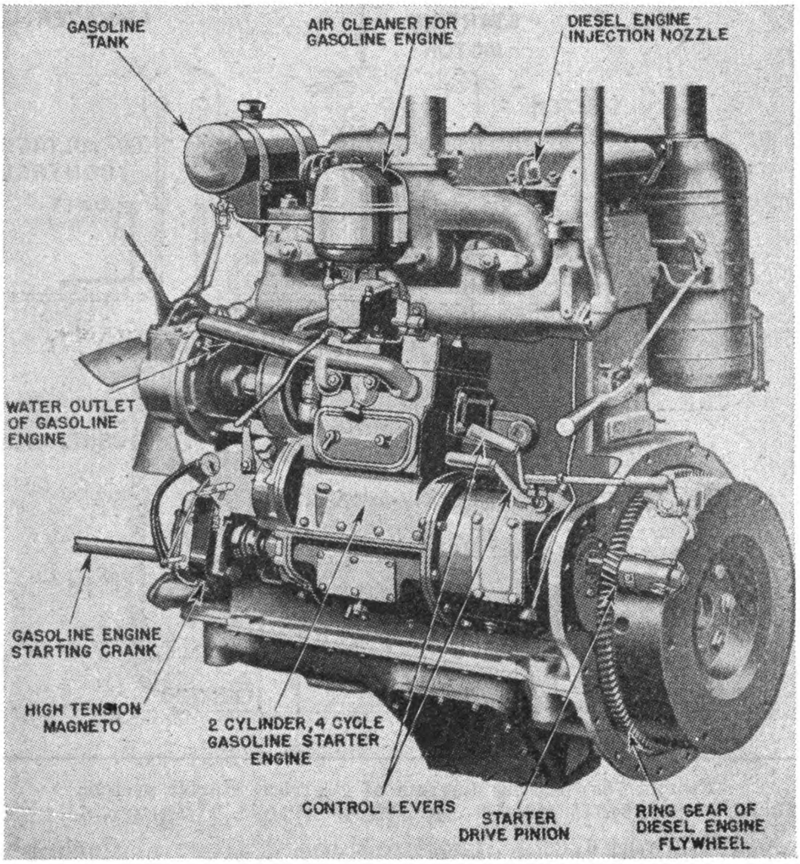



FIGURE 77.—Gasoline starter engine installation.

a passenger car engine but 12- and 32-volt high torque motors are necessary in Diesel automotive engines in order to keep the starting current within reason. The usual electrical equipment consists of storage batteries, generator, and starting motor, together with suitable voltage regulators, relays, etc. to regulate and protect the electrical system. It is customary to employ 6- or 8-volt batteries connected in series to provide the necessary current. The automatic Bendix drive is used for transmitting the power of the starting motor to the engine flywheel. A typical wiring diagram of the electrical system used for starting Diesel powered trucks is shown in figure 78.

*b.* Due to the high voltage of the starting circuit and the great amount of power available from the batteries, it is imperative that every precaution be observed in guarding against the possibility of a short circuit or a ground in the circuit. All wires should be of sufficient size to carry the electrical load to which they are subjected without overheating. All terminals and clips that are ordinarily

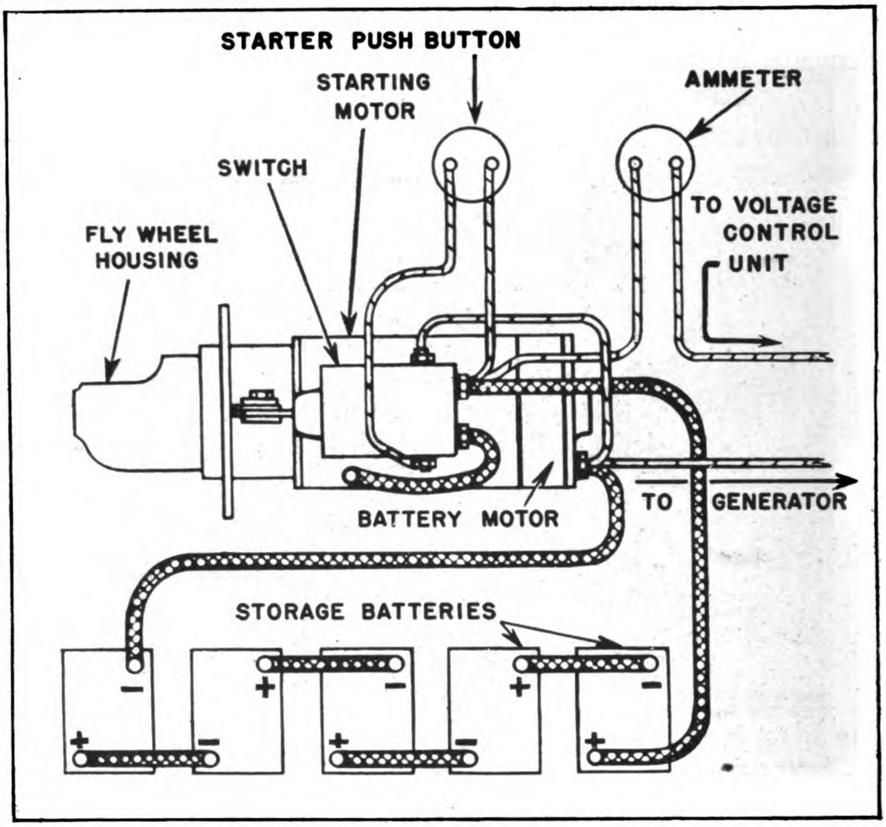



FIGURE 78.—Wiring diagram of electrical starter system.

left exposed should be insulated. Extra heavy insulation must be used on all wires and the wires must be supported at enough points to keep them from moving about and wearing through their insulation. Rubber boots, rubber tape, or friction tape and shellac should be used to cover all unprotected portions of the circuit.

**62. Miscellaneous.**—*a.* Conversion starting is employed in some Diesel engines by temporarily converting the engine to a spark ignition system during starting. The engines are equipped with a duplex intake manifold, a carburetor, and regular spark ignition equipment. Figure 79 shows an auxiliary combustion chamber which is placed

in communication with the working cylinder by opening an auxiliary intake valve. This lowers the compression and places the gasoline-air mixture in contact with the spark plug on the compression stroke. The starting lever opens a valve between the engine cylinder and the auxiliary chamber, raises the air valve to cut off the regular air supply and at the same time places the engine in communication with the gasoline carburetor, and engages the magneto. When the engine is cranked in the normal way (by hand or small electric starting motor) it runs as a gasoline engine for a few hundred revolutions

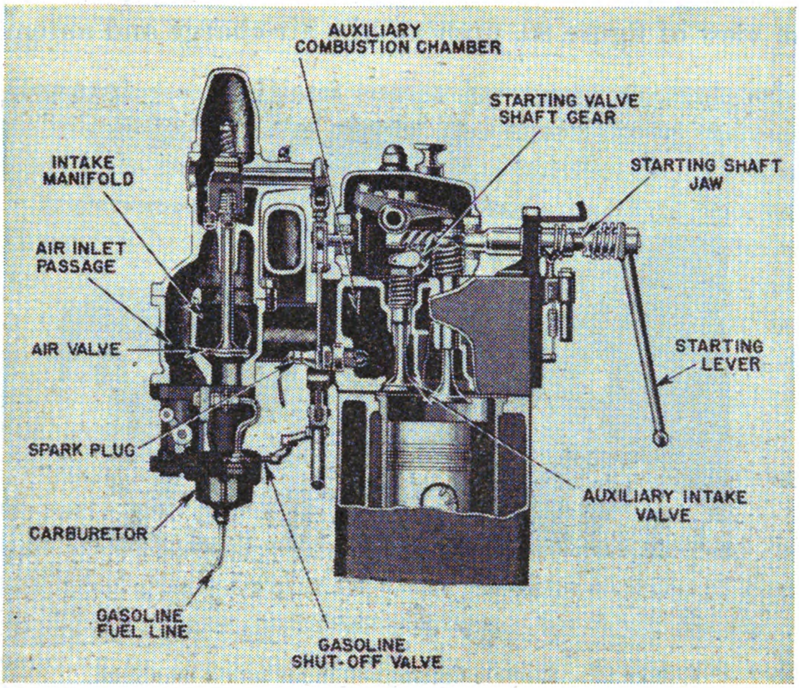



FIGURE 79.—Conversion starter system.

until it is thoroughly warmed up, at which time the starting lever is turned back to its original position. This turns off the gasoline starting equipment and allows the engine to operate as a full Diesel.

*b*. Hesselman type engines have a comparatively low compression and can be cranked by hand like a gasoline engine of corresponding size. In fact, the engine starts as a gasoline engine by injecting a small quantity of gasoline in the intake manifold. The gasoline is swept into the cylinder, the spark ignites it, and the heat of combustion warms the piston sufficiently after a few revolutions to vaporize the Diesel fuel and permit regular operation. No change-over is necessary.

*c*. When precombustion chambers or separate turbulence combustion chambers are used, the increased cooling effect, caused by greater surface contact and rotary motion of the air, makes engine starting difficult. Electric glow plugs are often used to get additional heat for starting. The auxiliary air chamber is sometimes cut off from the main chamber during starting to temporarily raise the compression pressure.

*d*. Electrical heating coils which are connected to the starting system in the air intake manifold of Diesel engines have been installed to aid starting at cold temperatures. The heater, shown in the phantom view of figure 80, preheats the air charge and automatically

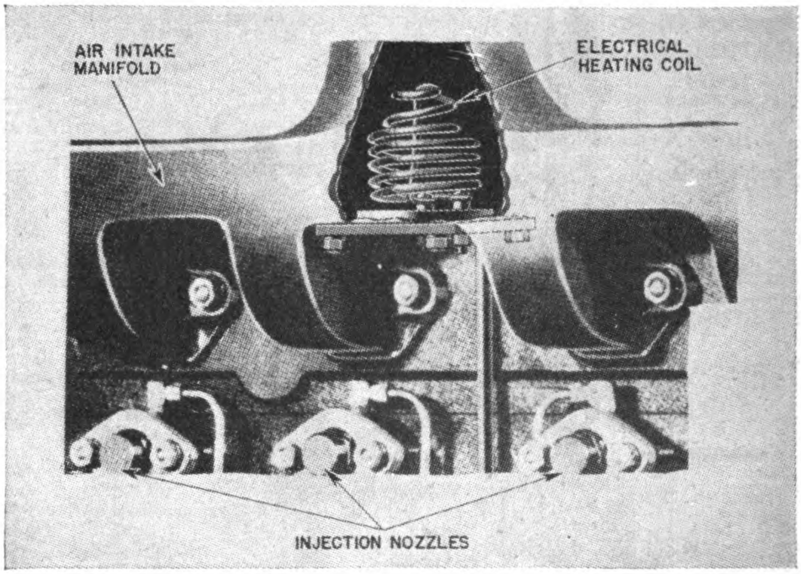



FIGURE 80.—Electric heating coil in air intake manifold.

disconnects and signals the operator by a light on the instrument panel of the truck when the air is sufficiently warm to start the engine. Because of their location in the intake manifold these heating coils are not subjected to destructive combustion temperatures as are glow plugs located in the combustion chamber.

*e*. Another recent development is the portable burner for preheating the circulating water, crankcase, and fuel lines to facilitate starting Diesel engines. The burner or heater uses regular Diesel fuel supplied under pressure by a hand pump incorporated in a small fuel tank mounted at the side of the engine. Since the burner is connected to this tank by a flexible hose the operator can move it about to warm up various parts of the engine such as the crankcase and fuel lines preparatory to starting. The burner can also

be inserted underneath a coil type water heater which is connected to the cooling system of the engine. Thus the cylinders are warmed up by circulating hot water through the water jacket of the engine.

## SECTION XI

## LUBRICATION



**63. General.**—*a.* A Diesel engine has many elements which slide or rotate in guides, and it is vital to the operation of the engine that there is not only an avoidance of abrasion but that there is a minimum of wear and friction. There are also such parts as the valve gear where there is a heavy pressure with very little relative motion of the parts, but here also lubrication eliminates abrasion and reduces the friction of rubbing. With respect to piston rings, an additional function is required of the oil; here the lubricating oil is depended upon not only to reduce the friction but also actually to seal the piston rings for gastightness. Thus the objectives of lubrication depend upon the local use of the oil and the mechanical functions of the adjacent parts which need lubrication.

*b.* High speed Diesel engines generally are designed for the use of about one SAE grade lighter oil than gasoline engines of corresponding size. Thus, where the latter might use an SAE No. 30 or No. 40 oil, depending on the temperature, the Diesel might use a SAE No. 20 or No. 30 oil. The trend toward better piston ring design and small clearances which has permitted the use of lighter oils in the automotive industry is being followed by Diesel builders. Although the selection of the right viscosity oil is largely a matter of experience, there are certain guiding principles that may be used in the selection of the proper lubricant. The higher the cylinder wall temperature, the greater oil viscosity needed. Thus a high compression engine requires a more viscous lubricant than a low compression engine. Likewise a poorly cooled Diesel engine requires a heavier lubricating oil than one having a good cooling system. Increase in speed increases the friction which by causing a rise in temperature reduces the viscosity of the oil. Hence, the speed of the engine influences the grade of oil to be used. The loads normally employed on Diesel bearings are not in themselves great enough to break down the oil film provided that

the oil is supplied at a rate sufficient to compensate for the flow from the bearing. If a bearing is fitted under proper clearance conditions and sufficient oil of the proper viscosity is supplied to keep the entire bearing surface continually covered with a film of oil, a straight mineral oil will provide adequate lubrication.

*c.* It is necessary to keep in mind that all Diesel engines employed in automotive service require lubricating oils of greater stability than gasoline engines. The oil should be nonsludging and nonemulsifying and it must be entirely suitable for this type of engine. Each engine builder makes recommendations along this line and these should be followed. It is important to see that the engine has plenty of good oil at all times.

*d.* Diesel engines are lubricated by the same highly developed method of pressure feed lubrication employed on gasoline engines (TM 10-570). The purpose of the lubrication system of the Diesel, as in the gasoline engine, is to provide a sufficient quantity of good oil to protect the moving parts and reduce friction to a minimum.

**64. Lubrication system.**—*a.* Figure 81 shows a typical lubricant circulating system used on a high speed Diesel. It is a force feed, wet sump type, wherein all the oil is carried in the bottom of the engine crankcase and is circulated by means of a gear type pump. The pump shaft is driven from the engine crankshaft by a drive gear at the timing gear end of the engine.

*b.* (1) Oil is drawn into the pump through the floating type oil strainer in the sump. A relief valve located on the discharge side of the pump maintains a fixed oil pressure of 30 pounds and bypasses excess oil. The oil passes from the pump, through the filter and the cooler, and into a manifold (oil line) drilled in the crankcase of the engine. The oil line distributes the oil to each of the main bearings. The circulation diagram shows how this is accomplished. From the main bearings the oil passes through the drilled crankshaft to the connecting rod bearings and through the drilled connecting rods to the piston pins. The cylinder walls are splash lubricated.

(2) Oil is also shown coming from the oil line to the crankshaft bearing, and flowing into the camshaft bearings. The front camshaft bearing supplies oil to the center of the camshaft for delivery to the hub of the camshaft gear. Oil is similarly delivered from the center of the idler gear shaft to its bearings. Drilled holes in the idler gear and camshaft gear hubs direct the flow to the gear teeth where oil is forced through holes to spray the entire timing gear train. Lubrication of the governor is usually supplied by a pressure lead from the

oil line. In all pressure systems every precaution should be taken against the possibility of loose connections.

**65. Oil pump.**—*a.* The gear pump used for circulating the oil and maintaining pressure in the system is similar to the rotary transfer pump described in paragraph 32. The method of driving the pump varies with different engines. It may be mounted on the side of the timing gear housing and driven by the timing gear train, located in the sump and driven by the camshaft, or in other suitable positions dictated by the engine design. When the pump is not located in the sump, it may lose its prime when the engine is overhauled and priming will then be necessary before it will function.

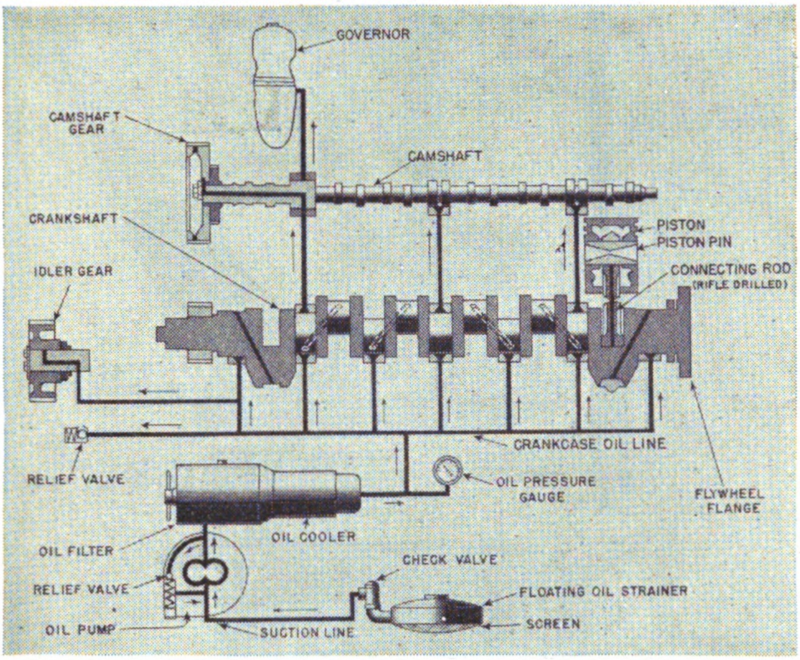



FIGURE 81.—Lubricant circulating system.

*b.* A two-stage oil pump is sometimes used to insure proper circulation of lubricating oil regardless of the angle at which the engine operates. The pump shown in figure 82 is of this type. The lower gear pump is used to force the oil through the system to the various bearings. The upper gear pump is the scavenging pump which draws oil through suitable pipes, protected by screens, from either the front or rear end of the engine. Even though the engine is tilted at extreme angles, the scavenger pump delivers oil to the lower pump for delivery to the engine.

**66. Oil filter.**—The lubricating oil of the Diesel engine is contaminated by sludge and carbon much more readily than oil in gaso-

line engines. For this reason the conventional lubricating oil filters suitable for gasoline engines are often not satisfactory for Diesels. Filters commonly used on Diesel engines are of four types: wire screen, metal or paper washer, fabric, and magnetic.

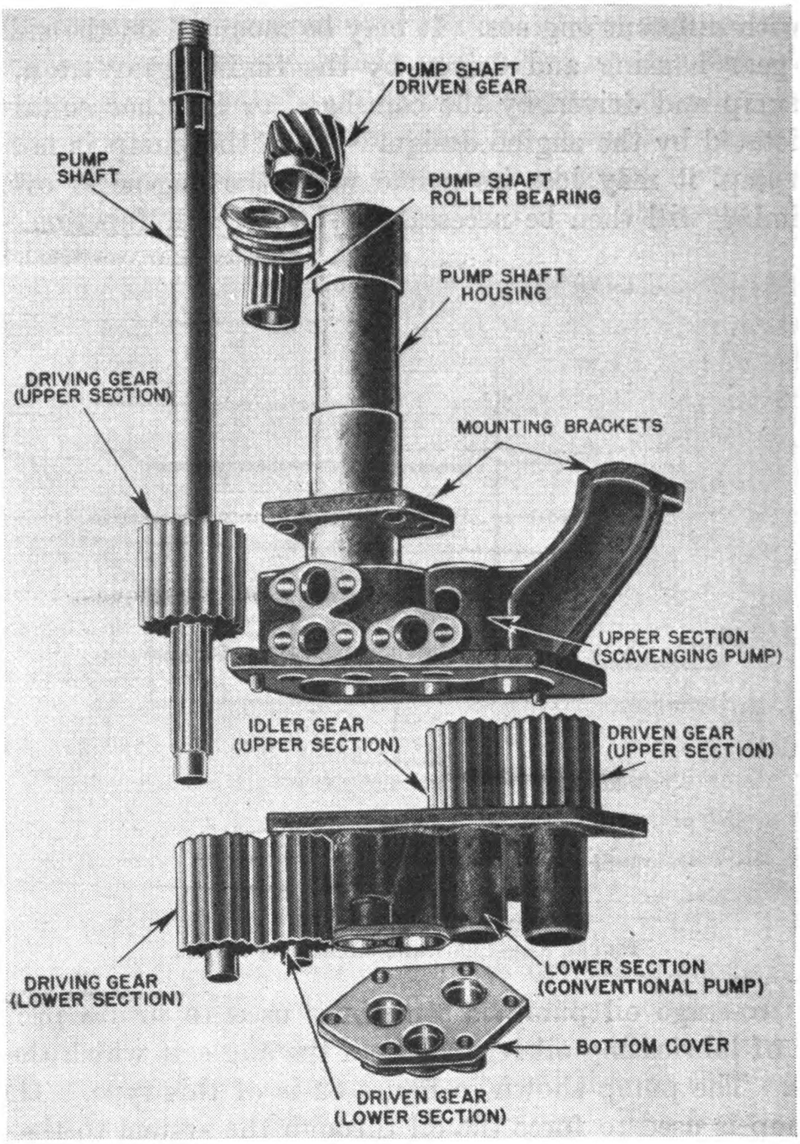



FIGURE 82.—Two-stage gear oil pump.

*a.* The *wire screen filter* may more properly be called a strainer of the floating type placed in the oil pan or sump and connected to the suction side of the oil pump. The wire screen has a small enough mesh to prevent the passage of anything that would damage the pump, but otherwise it is not designed to thoroughly clean the oil.

*b*. The *screen type filter* shown in cross section in figure 83 is widely used on Diesel engines. It consists of a shell enclosing a double filter element mounted on a base which is bolted to the engine. The filter elements are made of two (inner and outer) cylindrical screens with closed top and bottom. These screens are separated by small

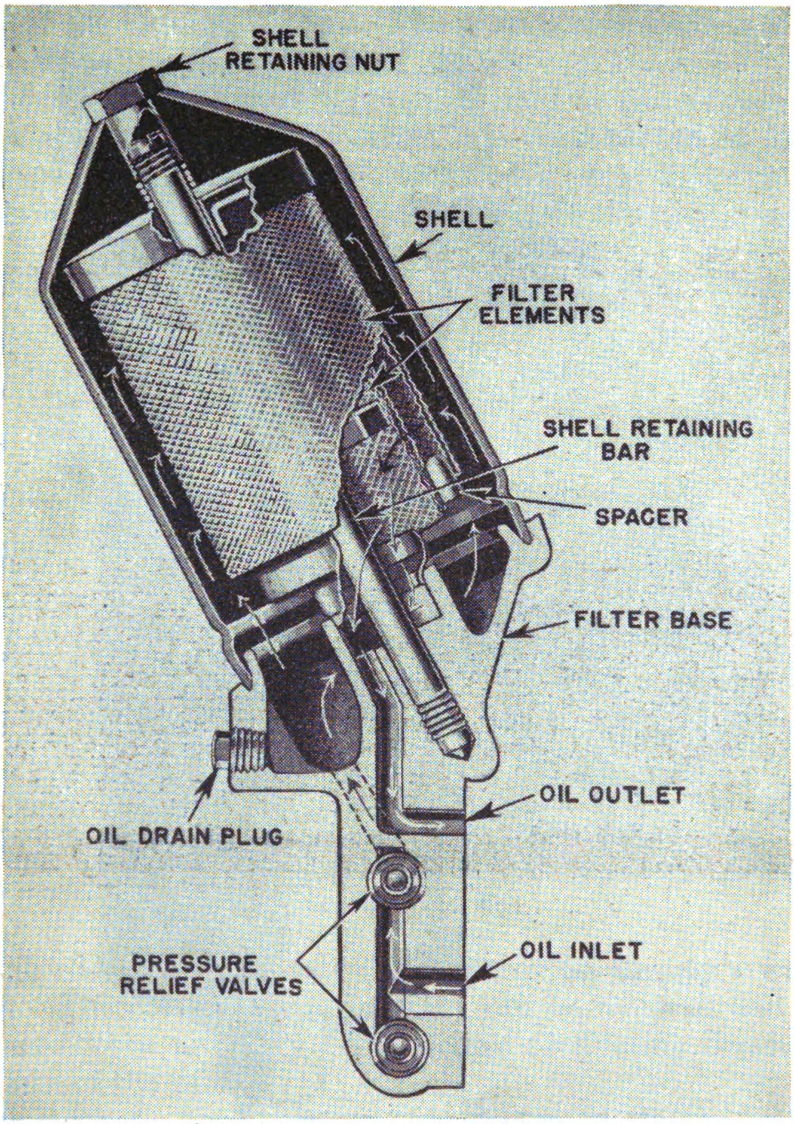



FIGURE 83.—Screen oil filter.

spacers located at the bottom. Oil is forced through the inlet passage of the filter base to the shell, where it flows from the outside to the inside through the filter elements. The fine mesh of the elements exclude particles as small as 0.003 inch. The clean oil flows down the center passage in the base to the outlet leading to the engine

parts to be lubricated. Two pressure relief valves located in the base provide a safety bypass in case the filter elements should become clogged due to neglect. These valves are calibrated to open at defi-

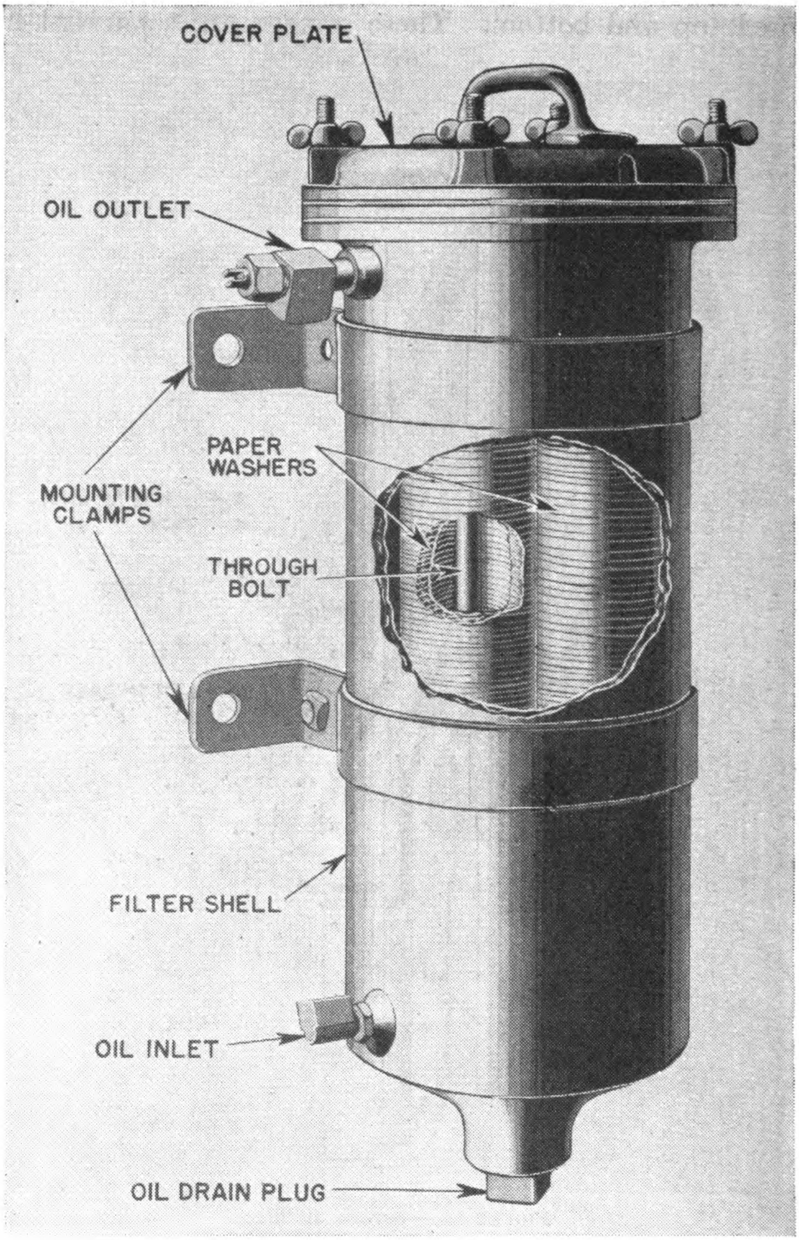



FIGURE 84.—Paper washer oil filter.

nite pressures which vary with different makes of engines. The filter elements can be replaced or cleaned by loosening the retaining nut and removing the shell.

*c.* The *washer filter* is another very efficient filter built with prepared paper washers stacked and held tightly together under spring pressure by a through bolt as illustrated in figure 84. Oil enters at the bottom of the filter shell and completely surrounds the washers. It requires considerable pressure to force the oil through from the outside of the washers to the inner hole where it flows to the outlet passage at the top of the shell. The filter is cleaned by temporarily reversing the direction of oil flow.

*d. Fabric filters* are made of woolen cloth or flannel bags held in place by a metal frame and inserted into the filter shell. By winding the bags around the frame as illustrated in figure 85 several bags can be fitted into the shell and thus more filtering area exposed

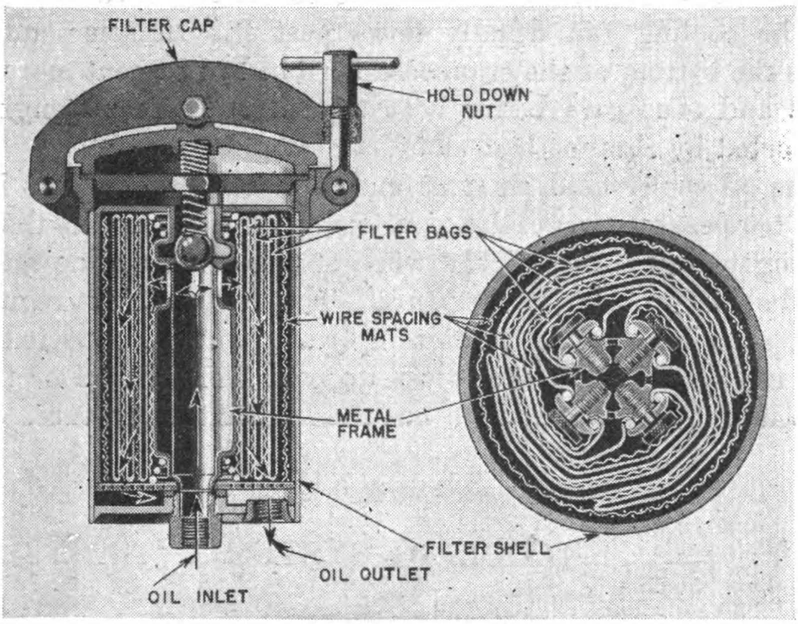



FIGURE 85.—Bag filter.

to the oil. The bags are separated from one another by a wire spacing mat. The entire filtering element can be removed and cleaned or replaced when necessary. The degree of filtering depends upon the texture of the fabric.

*e.* The *magnetic filter* is a recent development. A large percentage of solids found in lubricating oil is made up of metal particles which cause rapid wear. These particles may include products of the machining processes (fine turnings, chips, etc.) which have not been removed by the usual flushing methods, as well as particles representing worn metal parts of the engine. A magnetic filter consists of a stack of permanently magnetized screens enclosed in a

cylindrical casing. Although this filter offers very little resistance to the flow, it presents hundreds of feet of strongly magnetized edges to the oil. As these edges comb and recomb the oil, the metal particles from the oil are held firmly to the screen edges until the filter is cleaned.

**67. Oil cooling.**—*a.* It is as important to supply oil to the engine at the proper temperature as it is to supply clean oil. Much of the bearing friction heat is conducted away through adjacent metals, but the oil also carries away much of the heat. This oil, as it leaves the bearings, is appreciably higher in temperature than the crankcase. Some of the heat of the oil is transferred to the crankcase walls as it drains into the sump.

*b.* The crankcase has a very important cooling effect since the air from the cooling fan usually flows past it. In some automotive engines the bottom of the crankcase is ribbed to present more cooling surface and thus give better heat transfer. In many engines, the oil is cooled by this method alone.

*c.* The oil cooler used on some automotive Diesel engines is really an oil temperature regulator. It brings the oil up to the proper operating temperature quickly when starting the engine and maintains the oil at that temperature. The temperature regulator is simply an oil reservoir containing water tubes connected to the engine radiator. The water picks up heat from the oil or transfers heat to it, depending on which has the higher temperature.

## Section XII

## COOLING SYSTEM



**68. General.**—*a.* The cooling system of an engine might be called more descriptively "the heat controlling system," since its function is to regulate the engine operating temperature. When the engine temperature rises above the desired operating level, heat must be carried away by the cooling medium. If the engine is cold, as in starting, the cooling system must trap the heat produced so that the engine temperature will rise as quickly as possible to the normal operating level.

*b.* No new principles are involved in the cooling of Diesel engines. Forced circulation as used on conventional gasoline engines (TM 10–570) is considered essential for high speed automotive Diesels

due to the severe conditions encountered. This system consists of a radiator, fan, water pump, thermostat, and water jacket. Heat control is accomplished by keeping the cooling water circulating through the water jacket. When heat must be carried off, circulation is completed through the radiator where the heat dissipation is aided by the fan. When the engine temperature is lower than that required for normal operation, circulation is confined to the water jacket by the thermostat. Figure 86 illustrates a typical arrangement of a forced circulation cooling system as used on a Diesel truck engine.

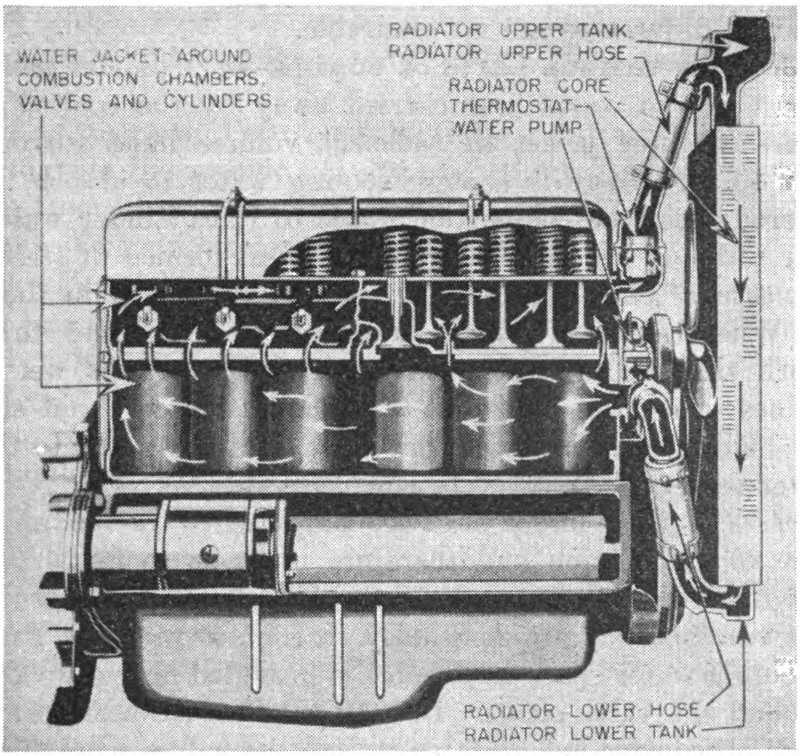



FIGURE 86.—Forced cooling water circulation.

*c.* A Diesel engine does not require as much radiator capacity as a gasoline engine of the same size because more fuel energy is converted into useful work. However, Diesel engines are usually equipped with the same size radiators as used on similar gasoline engines, but the speed and size of fans are reduced to compensate for the reduction in cooling requirements.

*d.* (1) The cylinder wall temperature must be kept sufficiently high so that combustion gases do not condense. The cooling water is usually kept at 160° F. to accomplish this. To assure the maintenance of this water jacket temperature, most Diesel engines are equipped with a heat operated bypass valve (thermostat) located

in the hot water outlet connecting the engine water jacket to the upper tank of the radiator. The thermostats are similar to those used on gasoline engines.

(2) The pump circulating the cooling water must maintain pressure at low speeds, and prevent excessive pressures at high speeds in order to provide effective control of the engine temperature. In automotive Diesel engines pump capacities average about one gallon per horsepower per minute. This rate of flow has been found to be satisfactory for maintaining a difference of 15° to 20° between the inlet and outlet water temperatures in most engines. Greater temperature differences are not desirable.

**69. Cooling various parts of engine.**—*a. Cylinder walls* dissipate most of the waste heat carried away by the cooling system. Therefore a water jacket of sufficient volume must surround the cylinder so that there is enough cooling water to absorb the heat transferred from the combustion space to the cylinder walls. The cylinder walls of the Diesel engine are often formed of steel tubing called sleeves. These sleeves are secured in position in the engine block. When the outer surface of the sleeve comes into direct contact with the cooling water, they are designated as wet sleeves. In engines using wet sleeves heat control is more rapid since the heat of combustion passes through the thin sleeve walls to the cooling water very rapidly.

*b. Valves* in the cylinder head are subjected to the maximum temperature of combustion and therefore must be cooled in order to prevent their distortion and failure. This is especially true of the exhaust valves which are constantly in contact with hot gases. As much cooling water space as possible is provided near the valve seats and around the valve stems. In some engines a water spray is directed on these very hot surfaces to cool the valves more effectively.

*c.* The *piston head* is also subjected to the high temperature of combustion and several methods of carrying off this heat have been devised. A simple transfer method is used in which the heat is dissipated through the thickness of the piston head to the piston rings where it is lost to the cylinder walls. Another practical method of cooling pistons is to use the lubricating oil. The oil under pressure used to lubricate the piston pin is forced out of a hole in the closed hub at the upper end of the connecting rod so that an oil spray strikes the underside of the piston head. Here the oil absorbs heat and falls back into the crankcase where the heat is dissipated.

## Appendix I

## GLOSSARY

For purposes of clarity and uniformity the following terms and definitions are used in this manual when discussing the Diesel engine:

*Acceleration.*—The average rate of change of an increasing velocity or speed.

*A. P. I.*—American Petroleum Institute. An arbitrary scale used to designate the specific gravity of fuel oils. Diesel fuels usually range from 24 to 36 A. P. I. gravity.

*Atomize.*—To reduce to extremely fine particles.

*Axially.*—Parallel to the center line of a cylinder or shaft.

*Axis.*—A center line. A line about which something rotates or about which it is evenly arranged.

*Babbitt.*—A soft antifriction bearing metal.

*Back pressure.*—The result of resistance to the normal flow of gases and liquids.

*Bore.*—The interior diameter of an engine cylinder. (*See* terminology on stroke.)

*British thermal unit (B.t.u.).*—A unit for measuring heat. One British thermal unit equals 778 foot-pounds of work (or energy). It represents the heat required to change the temperature of 1 pound of water through 1° Fahrenheit.

*Bypass.*—A separate passage which permits a liquid or gas to take a course other than normally used.

*Calorific value.*—Heat value of fuel measured by the metric system, calory equals .003968 B. t. u., or 1 B. t. u. equals 252 calories.

*Carbon residue.*—The carbon remaining after evaporating off the volatile portion of a fuel oil by heating it in the absence of air under controlled test conditions. It is an indication of the amount of carbon that may be deposited in an engine.

*Centrifugal force.*—The force acting on a rotating body which tends to throw it farther from the axis of its rotation.

*Cetane rating.*—A system of numbers for indicating the ignition quality of Diesel fuels.

*Chamfer.*—A beveled corner.

*Check valve.*—A device that permits passage of a fluid or gas in one direction only. It stops (or checks) reverse flow.

*Clearance.*—The space between a moving and a stationary part. Clearance is usually allowed between two surfaces to provide for expansion and contraction and for lubrication.

*Clearance volume.*—The amount of space confined within the engine cylinder and related parts when the piston is at its top dead center position.

*Coefficient.*—A ratio; a known factor or quantity that is always constant.

*Combustion chamber.*—The space within a cylinder in which the fuel mixture is burned.

*Compression.*—The act or result of pressing a substance into a smaller space. One of the events of an internal combustion engine cycle.

*Compression pressure.*—The amount of pressure resulting from the compression stroke of a piston when it has reached top dead center.

*Compression ratio.*—A ratio expressing the extent to which a fuel or air charge is compressed. It is a relationship between clearance and displacement volumes and is found as follows:

$$\frac{\text{Piston displacement} + \text{clearance volume}}{\text{Clearance volume}} = \text{compression ratio}$$

*Concentric.*—Having a common center.

*Condensation.*—The process by which a vapor is reduced to a liquid.

*Contraction.*—Becoming smaller in size. Usually, in metals, a result of cooling or a lowering of temperature.

*Cycle.*—A series of events, operations, or movements that repeat themselves in an established sequence.

*Cylinder, in-block.*—A group of cylinders cast as one piece.

*Detonation.*—The result of violent uncontrolled burning of a fuel in the combustion chamber.

*Diesel cycle.*—A cycle of events which occur in Diesel engines similar to gasoline (Otto cycle) engines except that air without fuel is compressed to a high pressure. At the end of the compression stroke fuel is injected into the hot compressed air and burns immediately.

*Distillation.*—Separation of the more volatile parts of a petroleum oil from those less volatile by vaporization and subsequently condensation.

*Dribbling.*—A characteristic of an injection nozzle in which the fuel seeps slowly from the nozzle tip.

*Eccentric.*—A circle not having the same center as another within it. A device mounted off-center for converting rotary motion into reciprocating motion.

*Efficiency, mechanical.*—The ratio between the brake horsepower (bhp) and the indicated or total horsepower (ihp).

*Efficiency, volumetric.*—The ratio of the volume of air or fuel mixture actually taken into the cylinder to the volume of the piston displacement.

*Energy.*—Capacity for doing work.

*Engine.*—A machine which produces power to do work, particularly one that converts heat into mechanical power. The term "engine" should be used in referring to the power plant of a motor vehicle, and the term "motor" should be used in connection with electric motors.

*Fit.*—A fit may be considered as the desired clearance between the surfaces of machine parts.

*Friction.*—The action between two bodies at the surfaces of contact, which opposes motion.

*Fuel pump.*—A small pump for delivering fuel to the engine. A Diesel fuel pump operates at a fixed ratio to engine speed and may be of the constant volume or of the metering type.

*Fulcrum.*—The support on which a lever turns.

*Governor.*—A device used to control speed (r. p. m.) of an engine.

*Heat.*—A form of energy.

*Heat units.*—The unit of heat (1 British thermal unit (B. t. u.)).

*Helical.*—A term used to describe gear teeth shaped like a helix.

*Helix.*—A line shaped like a screw thread.

*Horsepower.*—A unit for measuring power. It is the rate at which work is done. One horsepower is 33,000 foot-pounds per minute. (*See* Brake horsepower, Friction horsepower, and Indicated horsepower.)

> *Brake horsepower.*—Amount of net available power produced by an engine as measured at the crankshaft.
>
> *Friction (fhp) horsepower.*—The horsepower consumed by the engine in running itself; that is, the power lost within the engine due to its internal friction.
>
> *Indicated (ihp) horsepower.*—Total power developed by the engine; or brake horsepower (bhp) added to friction horsepower (fhp).

*Hunting.*—Erratic engine operation; caused by the inability of a governor to respond accurately to changes in engine speed.

*Hydraulics.*—The science of using liquids under pressure to do work.

*Idling.*—Engine running at lowest speed possible, without stalling.

*Impeller.*—The rotating part of a blower or pump which imparts motion to air or a liquid by forcing it outward from the center of the part.

*Inertia.*—The property of a body which causes it to persist in a state of rest or in uniform motion.

*Injection.*—The forcing of fuel oil into the combustion chamber of a Diesel engine by means of high pressure.

*Integral.*—The whole made up of parts; constituting a part of a whole necessary to completeness.

*Intermittent.*—Occurring at intervals.

*Jet.*—A metered opening in an air or fuel passage to control the flow of air or fuel.

*Journal.*—The finished part of a shaft which rotates in or against a bearing.

*Laminated.*—Made of thin layers such as "laminated shims," "laminated cores," etc.

*Lean mixture.*—A mixture in which the proportion of air to fuel is greater than the ideal.

*M. p. h.*—Miles per hour.

*Motor.*—Technically applied to an electric motor.

*Needle valve.*—A small plain or threaded rod having a conical or tapered point, operated within a jet to vary the flow of fuel through the jet.

*Otto cycle.*—A cycle of four events which occur in a gasoline engine in the following order: intake, compression, power, and exhaust.

*Poppet valve.*—A valve opened by the action of a cam and closed by a strong spring. This type of valve is used almost exclusively in the automotive industry.

*Port.*—An opening, hole or passage.

*Pour point.*—The lowest temperature at which fuel oil will just flow under controlled test conditions. It is an indication as to the suitability of the fuel for cold weather operation.

*Power.*—The capacity to do work.

*Radial.*—Radiating from a common center, as the spokes of a wheel.

*Reciprocating.*—A back and forth (or up and down) linear motion, such as the action of pistons in the engine.

*Rectilinear motion.*—Motion in a straight line.

*Rotary.*—Revolving or circular. Rotary motion is considered the opposite of linear reciprocating (up and down or back and forth) motion in power transfer.

*R. p. m.*—Revolutions per minute.

*Seat, valve.*—That part of the valve mechanism upon which the valve face rests to close the port.

*Servo-motor.*—A small hydraulic motor for operating heavy control mechanisms.

*Stability.*—Ability of lubricating oil to stand up without physical change under severe operating conditions.

*Stress.*—The forces exerted on, within, or by a body during either tension or compression. The opposing reaction of the interior elements of a body against forces tending to deform them.

*Stroke.*—The distance a piston travels up or down inside a cylinder.

*Temperature.*—The intensity (or degree) of heat.

*Thermodynamics.*—The theory of changing heat into mechanical work.

*Thrust.*—A stress or strain tending to push anything out of alinement.

*Tolerance.*—An allowable variation in dimensions. For example: A standard measurement of .025 with a tolerance of minus .003 or plus .003 indicated that dimensions of .022 or .028 are allowed.

*Torque.*—A twisting or wrenching effort. Torque is the product of force multiplied by the distance from the center or rotation at which it is exerted. For example: A force of 40 pounds applied on the end of a 1-foot pipe wrench would be 40 pounds × 1 foot, or 40 foot-pounds of torque. Similarly, 40 pounds of force exerted on the end of a 2-foot pipe wrench would be 40 pounds × 2 feet, or 80 foot-pounds of torque. This indicates why it is easier to unscrew a pipe coupling with the 2-foot wrench than with the 1-foot wrench, the torque incident to the 2-foot lever (wrench) being greater.

*Torsion.*—The deformation in a body caused by twisting.

*Vacuum.*—Result of reducing atmospheric pressure.

*Velocity.*—The rate of motion or speed of a body at any instant. Usually measured in miles per hour or feet per second or minute.

*Venturi.*—A tube with a narrowing throat or constriction to increase the velocity of the gas or fluid flowing through it.

*Viscosity.*—Internal resistance to flow. The fluid body of a liquid.

*Volatility.*—Ability of a liquid to vaporize or turn into gas.

*Work.*—The use of energy to overcome resistance.

APPENDIX II

## BIBLIOGRAPHY

The following sources have been consulted in the preparation of illustrations and text material for this manual. They contain more detailed information on Diesel engines than is contained herein, and it is suggested that it would be advantageous for the student to consult them as collateral reading.

*Diesel Engineering*, Vol. 6, by Howard E. Degler (1939); published by the American Technical Society, Chicago, Ill.

*Diesel Engines*, by J. W. Anderson (First Edition, 1935); published by the McGraw Hill Company, Inc., New York, N. Y.

*Diesel Engines*, by B. J. von Bongart (1938); published by D. Van Nostrand Company, Inc., New York, N. Y.

*Diesel Operation*—Fuels and Lubricants (1938); published by The Texas Company, New York, N. Y.

*Diesel Service Manual*, published by the Automobile Digest, Cincinnati, Ohio.

*Diesel—The Modern Power*, by Ralph A. Richardson (Revised Edition, 1939); published by General Motors Corporation, Detroit, Mich.

*Elements of Diesel Engineering*, by Orville Adams (1938); published by the Norman W. Henley Publishing Company, New York, N. Y.

*Engineering Bulletin HD-19* (1939); published by the Standard Oil Company, Chicago, Ill.

*Fuel Injection Equipment for Diesel Engines*, by G. W. Baierlein (1937); published by the American Bosch Company, Springfield, Mass.

*High Speed Diesel Engines*, by P. M. Heldt (Second Edition, 1936); published by P. M. Heldt, Nyack, N. Y.

*High Speed Diesel Engines*, by Arthur W. Judge (Second Edition, 1935); published by the D. Van Nostrand Company, Inc., New York, N. Y.

*High Speed Diesel Engines*, by L. H. Morrison (1937); published by the American Technical Society, Chicago, Ill.

*Internal Combustion Engines*, by R. L. Streeter and L. H. Lichty (1939); published by the McGraw Hill Company, Inc., New York, N. Y.

*Understanding the Automotive Diesel* (Second Printing, 1939); published by the Mack Trucks, Inc., New York, N. Y.

# INDEX



326564°—41——8

INDEX

INDEX



[A. G. 062.11 (4-18-41).]

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
*Chief of Staff.*

OFFICIAL:

E. S. ADAMS,
*Major General,*
*The Adjutant General.*

DISTRIBUTION:

B 1, 2, 4, 6, 7, 17 (2); R 1, 2, 4-7, 10, 17 (5); IBn 2-6, 9, 10, 17 (5); IC 2-6, 9, 10, 17 (5).
(For explanation of symbols see FM 21-6.)



U. S. GOVERNMENT PRINTING OFFICE: 1941

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - Price 20 cents